E. B. Chamberlain
from N. E. Bot. Club

NINETEENTH ANNUAL REPORT

OF

# THE MICHIGAN ACADEMY OF SCIENCE

PREPARED UNDER THE DIRECTION
OF THE COUNCIL

BY

G. H. COONS
CHAIRMAN, BOARD OF EDITORS

BY AUTHORITY

LANSING, MICHIGAN
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1917

## LETTER OF TRANSMITTAL.

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To Hon. Albert E. Sleeper, *Governor of the State of Michigan:*

Sir—I have the honor to submit herewith the XIX Annual Report of the Michigan Academy of Science for publication, in accordance with Section 14 of Act No. 44 of the Public Acts of the Legislature of 1899.

Respectfully,

I. D. SCOTT,

Ann Arbor, Michigan, June, 1917. Secretary.

# TABLE OF CONTENTS.

# PAPERS PUBLISHED IN THIS REPORT.

# ILLUSTRATIONS.



# FIGURES.

## OFFICERS FOR 1917-1918.

President, LeRoy H. Harvey, Kalamazoo.
Secretary-Treasurer, I. D. Scott, Ann Arbor.
Librarian, Crystal Thompson, Ann Arbor.
Chairman, Board of Editors, G. H. Coons, East Lansing.

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Geography and Geology, C. W. Cook, Ann Arbor.
Zoology, G. R. LaRue, Ann Arbor.
Sanitary and Medical Science, L. H. Cooledge, East Lansing.
Botany, C. K. Dodge, Port Huron.
Economics, F. T. Carlton, Albion.

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Dr. Chas. E. Marshall, East Lansing.
Professor Frank Leverett, Ann Arbor.
Dr. F. G. Novy, Ann Arbor.
Professor Wm. E. Praeger, Kalamazoo.
Professor E. A. Bessey, East Lansing.

## TWENTY-SECOND ANNUAL MEETING

OF THE

# MICHIGAN ACADEMY OF SCIENCE.

ANN ARBOR, MICHIGAN

March 28, 29, 30 and 31, 1917.

## GENERAL PROGRAM.

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### WEDNESDAY, MARCH 28

2:00 p. m. sharp. Council meeting, Room Z 231, Natural Science Building. Reports of committees.

2:30 p. m. General meeting of the Academy, Room B 207, Natural Science Building. Election of members.

3:00 p. m. Meeting of the following sections:

*Zoology*—Room Z 355, Natural Science Building.

*Sanitary Science*—Upper Lecture Room, New Medical Building.

*Botany*—Room B 207, Natural Science Building.

*Geography and Geology*—Room G 217, Natural Science Building.

8:00 p. m. Presidential Address, by Professor William H. Hobbs, "The Making of Scientific Theories." Auditorium, Natural Science Building. This lecture is open to the public.

9:00 p. m. Smoker, given by the Research Club in Alumni Memorial Hall.

### THURSDAY, MARCH 29

8:30 a. m. Council meeting, Room Z 231, Natural Science Building.

9:00 a. m. Meeting of sections for the reading of papers and nomination of vice-presidents.

1:30 p. m. Sections which have not completed the reading of papers may meet at this time.

8:00 p. m. Public lecture, by Professor Robert W. Wood of Johns Hopkins University, "Photographing the Invisible." Auditorium, Natural Science Building. This lecture is open to the public.

### FRIDAY, MARCH 30

8:30 a. m. Council meeting, Room Z 231, Natural Science Building. Election of officers and members.

10:00 a. m. Meeting of the Section of Economics, Lecture Room, second floor, Economics Building.

12:00 m. Luncheon for Biologists, Room B 100, Natural Science Building. Tickets may be secured at the door, price 25c.
2:00 p. m. Meeting of the Section of Economics.
6:00 p. m. Informal dinner at the Michigan Union for the Political Economists.
8:00 p. m. Public lecture, by Professor George Sarton, "Geographic Knowledge in the Time of Leonardo da Vinci." (Illustrated.) Auditorium, Natural Science Building.

Saturday, March 31

9:00 a. m. Meeting of the Section of Economics.
2:00 p. m. Meeting of the Section of Economics.

## SECTION OF ZOOLOGY

Robert W. Hegner, Chairman

Room Z 355, Natural Science Building

Wednesday, March 28, 3:00 p. m., and
Thursday, March 29, 9:30 a. m. and 1:30 p. m.

### Symposium on the Method of Evolution

1. From the standpoint of paleontology, by Professor E. C. Case.
2. From the standpoint of zoogeography, by Professor Alexander G. Ruthven.
3. From the standpoint of conchology, by Dr. Bryant Walker.
4. From the standpoint of comparative psychology, by Professor John F. Shepard.
5. From the standpoint of genetics, by Professor A. Franklin Shull.

### Papers on Methods

1. A method of cataloging and filing photographic negatives and prints, by Crystal Thompson.
2. Some remarks on the preservation of Reptiles and Amphibians for museum purposes, by Alexander G. Ruthven.
3. Methods of collecting Formicidae for museum purposes, by Frederick M. Gaige.
4. Notes on ostrich farming in northern latitudes, by Harry C. Fortner.
5. Some methods of preparing a study collection of zoological specimens, by Peter Okkelberg.
6. Some methods for the culture of microorganisms, by George R. La Rue.
7. The preparation of insects for exhibition purposes, by Robert W. Hegner.
*8. Terraria and balanced aquaria in the laboratory, by Elizabeth L. Thompson.
9. Methods of recording fauna data, by Grace Powers.
10. Methods of taking a bird census, by H. B. Sherman.
11. A simple method of projection with a compound microscope, by A. G. Papworth.

*Papers marked with a * are printed in this report.

### Miscellaneous Papers

*1. The occurrence of a supernumerary ocellus in Planaria maculata, by Bertram G. Smith.
2. The classification and distribution of the Ancylidae, by Bryant Walker.
3. The results of the Shiras Expedition to White Fish Point, Michigan. Preliminary report on the Coleoptera. A. W. Andrews.
4. A list of the Coleoptera taken by the Walker-Newcomb Expedition to Nevada, by A. W. Andrews.
*5. Amphibians and Reptiles of the Douglas Lake (Michigan) Region, by Max M. Ellis.
6. A new Salamander from Washington, by Helen Thompson Gaige.
7. The birds of the White Fish Lake Region, Alger County, by Norman A. Wood.
8. Epidermal sense organs in the tadpoles of Rana clamitans, by Wm. K. Bowen.
9. Is singing in mice a sex-linked character? Robert W. Hegner.
10. The evolutionary significance of genetic factors, by Robert W. Hegner.
11. Notes on parasites in the fish of Douglas Lake, by George R. La Rue.
12. Studies on the life history of a hickory beetle, Chramesus icoriae, by T. H. Hubbell.
*13. A contribution to the biology of the Protozoa, by A. G. Papworth.
14. The possibilities of the Biological Station at Douglas Lake, Michigan, by O. C. Glaser.
15. The Birds of a Salt Marsh, by Max M. Peet.

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## SECTION OF GEOLOGY AND GEOGRAPHY

L. P. Barrett, Chairman

Room G 217, Natural Science Building

Wednesday, March 28, 3:00 p. m., and
Thursday, March 29, 9:00 a. m. and 1:30 p. m.

1. Some Problems of Michigan Geology. 30 minutes. R. A. Smith and L. P. Barrett.
2. Erosion Forms in two square miles near Mt. Pleasant, Michigan, as shown by a 5-Foot Contour Map on Scale of 1:6000. 25 minutes. R. D. Calkins.
3. Report of Progress on the Stratigraphy and Paleontology of the Lower and Middle Silurian of Michigan. 20 minutes. G. M. Ehlers.
*4. The Geographer's Interest in Soil Surveys. 20 minutes. C. O. Sauer.
5. Old Drift of the Cordilleran Ice Sheet. 15 minutes. Frank Leverett.
6. Mirabilite from Michigan. 10 minutes. Albert B. Peck.
7. Altitude of the Troposphere Ceiling in Relation to the Fixed Glacial Anticyclone over Greenland. 15 minutes. W. H. Hobbs and Helen M. Martin.
8. Exhibit of Minerals and Rocks Mineralogical Museum. 30 minutes.

*Papers marked with a * are printed in this report.

1:30 P. M.

9. Some Unusual Crystals of Native Copper. 10 minutes. E. H. Kraus.
10. The Henry R. Ford Well at Dearborn, Michigan. 15 minutes. R. A. Smith.
11. The Effect of Hidden Masses of High Density on Anomalies of Gravity. 10 minutes. W. H. Hobbs.
*12. The Prospects of Oil Being Found under the Ontario-Ohio-Michigan Section of Lake Erie. 15 minutes. Thomas Nattress. Read by R. A. Smith.
13. The Environment of the Vertebrate Fauna at Denton, Ohio. Lantern. 20 minutes. E. C. Case.
*14. Glacial Lakes and their Correlative Ice Borders in the Superior Basin. 20 minutes. Frank Leverett.
*15. Some New Thermo-Optical Observations on Gypsum and Glauberite. Dr. E. H. Kraus and Dr. A. B. Peck.

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## SECTION OF AGRICULTURE

J. F. Morgan, Chairman

Room G 321 Natural Science Building

Thursday, March 29, 9:00 a. m. and 1:30 p. m.

1. A Few Observations of the New Federal Farm Loan System. Geo. W. Dowrie.
2. Federal Farm and Loan Act. W. O. Hedrick.
3. Elementary Facts Regarding Relations of Birds to Agriculture (Illustrated). R. W. Hegner.
*4. Eugenics and the Agricultural Community (Illustrated). O. C. Glaser.
5. The Normal School and its Relations to Agriculture. Myron A. Cobb.
6. Sanitation of Rural Homes. W. C. Hood.
7. Pumping Marl. H. H. Musselman and O. E. Robey.
8. Country Roads. J. J. Cox.
*9. Rural Sanitation. Ward Giltner.

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## SECTION OF SANITARY AND MEDICAL SCIENCE

Herbert W. Emerson, Chairman

West Lecture Room, Medical Building

Wednesday, March 28, 3:00 p. m., and
Thursday, March 29, 9:00 a. m. and 1:30 p. m.

1. The Wasserman Reaction. Dr. C. C. Warden.
2. The Pasteurization of Milk. Mr. C. H. Chilson.
3. Peptone. Professor F. G. Novy.
*4. Cheese Poisoning. Mr. William Levin.
5. Free Chlorine in Water. Dr. Roy Pryer.

*Papers marked with a * are printed in this report.

6. The Sanitary Regulation of Waters of the State. Professor W. C. Hoad.
7. Further Studies on Bact. abortus Infected Cows' Udders. Mr. L. H. Cooledge.
8. The Transmission of Bact. abortus to New-Born Calves through the Ingestion of Milk. Mr. I. F. Huddleson.
9. Methods of Destruction of Organic Matter in Testing for Arsenic in Toxicological Examinations. Professor V. C. Vaughan.
10. Typhoid Immunity. Mr. J. S. Chambers.
*11. Anaphylatoxin and Amino Acids. Mr. W. M. German.
12. Anaphylatoxin and Serum Fractions. Mr. A. H. Eggerth.
13. Organ Extracts. Mr. N. R. Smith.
14. The Susceptibility of the Prairie Dog to Rabies. Dr. Geo. Walters.

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## SECTION OF ECONOMICS

F. T. Carlton, Chairman

Lecture Room, Second Floor, Economics Building

FRIDAY, MARCH 30, 10:00 A. M. AND 2:00 P. M., AND
SATURDAY, MARCH 31, 9:00 A. M.

1. Railway Maintenance of Way Expenses and Cost Accounting. A. Bradley (University of Michigan).
*2. The Future of the Country Church. Robert Phillips (University of Michigan).

2:00 P. M.

3. Effect of the European War upon the Supply of Capital and the Rate of Interest in the United States. David Friday (New York University). Discussion opened by F. M. Taylor (University of Michigan).
4. Descriptive Economics. H. C. Adams (University of Michigan).

SATURDAY, 9:00 A. M.

5. Labor Income Scheme of Farm Business Analysis. W. O. Hedrick (Michigan Agricultural College).
*6. The Relation of Government to Economic Efficiency. E. H. Ryder (Michigan Agricultural College).
7. Some Tendencies in American Municipal Indebtedness. F. E. Clark (University of Michigan).

*Papers marked with a * are printed in this report.

## SECTION OF BOTANY

G. H. Coons, Chairman

Room B 207, Natural Science Building

Wednesday, March 28, 3:00 p. m., and
Thursday, March 29, 9:00 a. m. and 1:30 p. m.

*1. The Effect of Various Conditions of Shade and Moisture upon the Growth of Some Coniferous Seedlings. Paul C. Kitchin. 15 minutes.

2. Woodlot Studies. Prof. O. L. Sponsler. 30 minutes.

3. The Taxonomy of the Genus Mucor. Dr. A. H. W. Povah. 10 minutes.

*4. Unreported Michigan Fungi for 1914-1915. Dr. C. H. Kauffman.

*5. Hosts and Woody Substrata of Basidiomycetes Occurring in Michigan. Dr. C. H. Kauffman.

6. A Parasitized Mucor. F. B. Cotner.

7. A Segregate of the Genus Sphaeronema. Leon Leonian.

8. (a) A Peculiar Vegetative Growth in an Ascomycete.
   *(b) Polyembryony in Quercus alba.
   *(c) Intra-microsporangial Development of the Tube in the Microspore of Pinus sylvestris. Prof. LeRoy H. Harvey. 15 minutes.

*9. Notes on Michigan Collections of Myxomycetes. Prof. Henry C. Beardslee. 10 minutes.

*10. Physiological Balance in the Soil Solution. Dr. R. P. Hibbard. 10 minutes.

11. Experimental Methods in Plant Nutrition: The Influence of Methods upon Physiological Responses. Dr. R. P. Hibbard. 10 minutes.

*12. The Relation of Temperature to Crops. D. A. Seeley.

13. The Big Trees of California. Dr. H. A. Gleason. 20 minutes.

*14. Ecology of the Crystal Lake Bar Region. W. G. Waterman. 30 minutes.

15. A Coniferous Sand-dune in Cape Breton Island, Nova Scotia. Prof. LeRoy H. Harvey.

16. A Prairie near Ann Arbor. Dr. H. A. Gleason. 5 minutes.

17. A Peculiar Type of Succession Caused by Polytrichum. Dr. H. A. Gleason. 10 minutes.

*18. The Forest Associations of Wayne County, Michigan. Prof. Forest B. H. Brown. 20 minutes.

*19. The Flora of a Wayne County Salt Marsh. Prof. Forest B. H. Brown.

*20. Systematic Botany. Dr. W. J. Beal.

*21. Young, H. C., and Cooper, E. H. A Method for Determining the Fungicidal Coefficient of Lime-Sulphur and other Common Fungicides.

22. A Short Sketch of Early Botanical Exploration in Michigan. Prof. H. T. Darlington. 10 minutes.

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*Papers marked with a * are printed in this report.

*23. The Phylogeny of the Grasses. Prof. E. A. Bessey.

24. Extracts from Alexander's Manuscript on the Genus Helianthus. Samuel Alexander.

26. Elementary Species of Oenothera in the Michigan Flora. H. H. Bartlett.

26. Notes on the Sedges of Northern Michigan with Demonstration of Specimens. Lois E. Smith. 10 minutes.

27. Observations on the Native Flowering Plants, Ferns and Fern Allies of Michigan:

    (1) The Tuscola County Flora.

    (2) The Chippewa County Flora.

    (3) The Schoolcraft County Flora.

    (4) The Shore Plants of Eastern Michigan. C. K. Dodge.

*28. New Species and Varieties from Michigan. O. A. Farwell. (By title.)

*31. Flora of the Detroit Zoological Tract. John M. Sutton. (By title.)

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*Papers marked with a * are printed in this report.

# ADDRESS OF THE PRESIDENT OF THE MICHIGAN ACADEMY OF SCIENCE.

Delivered March 28, 1917, at the Auditorium,
Natural Science Building.

## THE MAKING OF SCIENTIFIC THEORIES*.

BY WILLIAM H. HOBBS.

The ancient Hebrews conceived the earth to be a disk hemmed in on all sides by mountains and surmounted by the crystal dome or firmament of the "heavens." This covered disk floated upon "the waters under the earth" and from the "windows of heaven" waters were poured out upon the "thirsty earth" from another reservoir which was above the firmament. To the denizen of the humid temperate regions it is perhaps a little difficult to see how this theory could have come into existence. The rains with which he is so familiar are showers, and they suggest not so much windows in the sky as they do a ceiling with innumerable perforations or some other glorified sprinkling device. To the Children of Israel the phenomenon of showers was unknown, for the rains to which they had become accustomed both during their wanderings in the desert of Sinai and in Palestine were of the local downpour or cloudburst type, the characteristic precipitation of the arid lands. So also their country was one in which earthquakes have been frequent, and they were not unaccustomed to seeing the earth open and water shoot upward from the fissures in much the same manner that it spurts into the hold of a ship from the opening of a seam. This oft-observed phenomenon is with little doubt responsible for the conception of the "waters under the earth" referred to in the twentieth chapter of Exodus. We see, therefore, that this crude theory of the world which was held by the early Hebrews and which appears to us so fantastic, was, after all, based upon facts, but like many theories which have followed it, upon too small a body of fact to supply a firm foundation.

It has often been said that the theories so tenaciously held by one generation are abandoned by the next. To a large extent this has been true of the past, and the explanation is in part that scientists are not less fallible than others, but are subject to like limitations in prejudice, in undue reverence for authority, in regard for the science vogue of

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19th Mich. Acad. Sci. Rept. 1917.

their time, and in many other conditions. To an even greater degree the overturning of scientific doctrines has been due to the failure of both the scientists and their critics to distinguish clearly between legitimate theory within those fields where views may be rigidly tested, and audacious conjectures which have been offered under the verisimilitude of facts to explain problems whose complete solution belongs to the remote future, if they may not be regarded as insoluble by any methods which have yet been discovered.

The process of eruption within a volcanic vent as regards its physical and chemical aspects offers a problem which, though by no means simple, may yet be subjected to observation and experimentation and doubtless belongs to the realm of soluble scientific problems. The materials present at the earth's center and their peculiar state of aggregation, are by contrast very largely a subject of conjecture, and attempts to class these problems together lead to inexcusable confusion.

A theory has been defined as an explanation founded upon inferences drawn from principles which are established by evidence. By contrast the hypothesis is a supposition as yet untested. The working hypothesis of the scientist occupies an intermediate position and aims to explain, at least in part and better than any other, a set of related phenomena which are already known, and it is considered to be in a probationary stage until confirmed through rigid tests the nature of which is suggested by the hypothesis itself. When so examined it may be found wanting; but, if well founded, experimentation is likely to result in its improvement by pruning of error quite as much as through enlargement of the body of truth which it contains.

The inheritance of knowledge by the ancients was, compared to ours, small indeed; and with their limited resources in materials and in methods of investigation, even more than we, they saw "through a glass darkly." It was therefore but natural that the theories which they evolved should have been largely the product of introspective reasoning. In consequence it was in the field of mathematics that they achieved their greatest triumphs, and as an inheritance a mathematical language was common to other fields of science even late in the seventeenth century. Viewing the marvels of the universe with their limited outfit of exact knowledge, the ancient philosophers invoked the supernatural and the mysterious to explain whatever was baffling and otherwise incomprehensible. Without books the dissemination of knowledge was limited to the narrowest channels and was accomplished by the disciples of each leader of thought, who was thus under the temptation of finding an answer to all questions and founding an individual school of philosophy.

With the invasions of the barbarian Huns and the Germanic tribes in the fifth century of the Christian era, there ensued the eclipse of civiliza-

tion which we are accustomed to refer to as the "Dark Ages." Out of the darkness of these centuries of intellectual stagnation we catch a glimpse which indicates that individual minds were still active in their search for the truth.

It is the twentieth day of June in the year 1320. The bells of Verona are ringing in the bright Sabbath morning and the crowd is saluting with respect a tall and serious figure—the great Dante—who with slightly bowed head is entering the chapel of Santa Helena. Dante has today invited the whole educated world of Verona to assemble in this chapel and listen to his discourse entitled "*De acqua et terra.*" He proposes to discuss the relative position of land and sea, and as he tells us himself, every one came at his bidding, "with the exception of a few, who feared by their presence to confirm the exceptional importance of others." . . .
With a gift for picture-writing never before equaled he has led his astounded contemporaries up to the abode of the saints and down into the depths of the lower world. Now today he is returning to the starting-point of his most powerful creation, to the critical examination of that which is greater than all the conceptions of poetry—the actual ordering of the universe.

Dante argued cogently for the spherical form of both the earth and the seas, and in accounting for the elevation of the land areas above the oceans, he even offered an early hint of the law of gravitation. The earth, he argued, can not elevate itself; nor can the cause be water, fire or air. He therefore suggested that the fixed stars might exercise this influence *"after the manner of magnets."*

The new era which opened with the revival of learning after a thousand years of stagnation, was one dominated by new considerations within the realm of thought. The keynote of the period was the dominating influence of the Christian church, and for centuries all thinkers were required to make their expressions conform to the dogmas of the church of Rome. The emancipation supposed to have arrived with the Protestant Reformation was a partial one only, and complete freedom of thought was not secured until the modern period of science was ushered in in the latter half of the nineteenth century.

Living as we do when few obstacles are opposed to a full and free expression, it will be profitable to review by means of examples the position of science in the sixteenth and seventeenth centuries. In declaring his belief in the heliocentric theory of the planets which Copernicus had promulgated, Galileo in 1597 wrote cautiously to Kepler:

It explains to me the cause of many phenomena which according to the generally accepted view are entirely incomprehensible. I have assembled many arguments for combatting the latter, but I do not dare to bring them into the light of publication. I would certainly risk it if there were more men like you.

With the telescope which he invented Galileo nightly studied the heavens from his little tower in the outskirts of Florence, and to his

friend he unburdened his soul in unbounded admiration for the works of his Creator. He writes:

> The prohibition of science would be contrary to the Bible, which in hundreds of places teaches us how the greatness and the glory of God shine forth marvelously in all His works, and is to be read above all in the open book of the heavens. And let no one believe that the reading of the most exalted thoughts which are inscribed upon these pages is to be accomplished through merely staring up at the radiance of the stars. There are such profound secrets and such lofty conceptions that the night labors and the researches of hundreds and yet hundreds of the keenest minds, in investigations extending over thousands of years would not penetrate them, and the delight of the searching and finding endures forever.

From this revelation of intellectual exaltation in one of the greatest apostles of science of all time, it is necessary to turn to a far different scene staged in one of the dark chambers of the Inquisition, if we would correctly interpret the spirit of his age. Bowed with years and threatened with the cruel torture, Galileo is seen kneeling before the crucifix and repeating in broken sentences the dictation of his persecutors:

> I bow my knee before the Honorable General Inquisitors, and touching the holy gospels I do promise that I believe and in future always will believe whatever the church holds and teaches for the truth. I was commanded by the Holy Inquisition that I should neither believe nor teach the false doctrine of the motion of the earth and the stationary attitude of the sun, because they are contrary to the Holy Scriptures. In spite of it I have written and caused to be printed a book in which I teach this cursed doctrine and have brought forth arguments in its favor. I have on this account been declared a heretic and worthy of contempt.
>
> In order now to redeem myself in the eyes of every true Christian who with justice must hold me in contempt, I forswear and curse the errors and heresies referred to, and above all every other error and every opinion which is contrary to the teaching of the Church. Also I swear in future never either in spoken word or in writing to express anything on account of which any one could have me in like contempt, but I will, if I anywhere find or suspect heresy, reveal it at once to the Holy Tribunal.

It is not pleasant to dwell on the extreme conditions which determined the making of theories at this period and which continued for fully a hundred years beyond the time of Galileo. For advocating the Copernican doctrine Giordano Bruno was burned at the stake. More prudent, de Maillet left his theories of nature to be published only after his death and then with his name disguised as Telliamed through printing the letters in reverse order; while Scheuchzer avoided persecution by describing as a human victim of the Noachian deluge a gigantic fossil salamander, and thus became the butt of succeeding generations. Steno, "the wise Dane," through enjoying the favor of a powerful Christian prince, was more fortunate than most of his contemporaries, and has

left us in his "Prodromus" one of the great scientific legacies of his age, now accessible to all through the excellent translation from the Latin by Professor Winter.

Inductive methods of reasoning came to play a larger part in the construction of theories as the control by both branches of the Christian church began to be relaxed. The feeling of relief from restraint brought, however, a reaction in what was almost an epidemic of theories characterized by a carelessness of construction and an insecurity of foundation that were surpassed only by the ardor and the vindictiveness with which they were defended. The latter half of the eighteenth and the first part of the nineteenth centuries was thus a period characterized by notable controversies in science which affected the greater part of Europe. Theories were attacked or defended with almost fanatical bitterness, the aim of the advocates of each theory being apparently less to arrive at the truth than to win in the struggle. Geologists were divided into two hostile camps over the origin of basalt; the Neptunists led by the Freiberg school of Werner in Germany claiming that it was a chemical precipitate in the ocean, and the Vulcanists who followed James Hutton of Edinburgh and believed the rock to be a product of the earth's internal heat. National boundaries were largely broken down and some of the most pertinacious and vindictive of the Wernerians were to be found in the British Isles.

On the other hand, the Neptunists had to meet in Germany a formidable champion of vulcanism in the poet Goethe, who, like Dante five centuries earlier, had a keen interest in science. For a time the bone of contention was found in a small hill near Eger in Bohemia, known as the Kammerbühl, a hill which Goethe stoutly maintained was "a pocket edition of a volcano." He suggested a simple method by which the question might be settled, and proposed that a tunnel should be driven into the hill to its center. If the mountain was a volcano, as he believed, a plug of basalt should be found occupying its axis. A wealthy friend, Count Casper von Sternberg, undertook extensive excavations, which when completed in 1837 abundantly proved the correctness of the poet's position.

Another great controversy was waged over the theory of the German geologist von Buch, known as the "Elevation Crater Theory," which assumed that volcanoes were pushed up in much the same manner as is the cuticle in the formation of a blister upon the body. Like the theory of the Neptunists, this doctrine was overthrown as soon as inductive methods of examination were applied to it.

Two doctrines of geology which were destined to play a large rôle in the history of science were developed in France. The "pentagonal

network" theory of Élie de Beaumont furnished the age of every range of mountains from the direction of its trend referred to the cardinal points; while the cataclysmic theory of Cuvier held that the earth's history had been punctuated by great cataclysms resulting in the destruction of all life upon the globe and followed always by a recreation of new faunas and floras. These doctrines, like those emanating from Germany, were destined to succumb to the rigid tests of the observational methods.

The control of scientific theory by the Church whenever it felt that its doctrines had been invaded was, if less formal and direct, none the less potent even as late as the latter half of the nineteenth century. This became apparent so soon as attacks began to be made upon the theory of catastrophism, for this theory was regarded as harmonizing with the biblical account of the creation. The evidence for the overthrow of this doctrine had been long collecting by a group of giants in science which developed in England toward the middle of the nineteenth century and which included Darwin and Huxley, Wallace, Lyell and Hooker. In the field of geology Lyell's theory of uniformitarianism was the counterpart of evolution in the organic world.

The battle was joined in 1859 with the appearance of the "Origin of Species," and it was fortunate for the scientific world that the crisis brought to the front a Huxley who could face "such a storm of wrath and flood of contumely as might have overwhelmed a less resolute and clear-headed champion." Gifted with a clarity of thought and expression and a vigor of utterance which are without a parallel in the whole field of science, Huxley had an utter contempt for dishonesty in thinking and little patience with mere meta-physical abstractions. To his friend Kingsley in one of the most remarkable of all his writings he says:

> I have champed up all that chaff about the ego and the non-ego, about noumena and phenomena, and all the rest of it, too often not to know that in attempting even to think of these questions the human intellect flounders at once out of its depth.

He correctly gauged the nature of the struggle which was coming and to Darwin he wrote on the appearance of the "Origin of Species":

> I trust you will not allow yourself to be in any way disgusted or annoyed by the considerable abuse and misrepresentation which, unless I greatly mistake, is in store for you. Depend upon it, you have earned the lasting gratitude of all thoughtful men. And as to the curs which will bark and yelp, you must recollect that some of your friends, at any rate, are endowed with an amount of combativeness which (though you have often and justly rebuked it) may stand you in good stead. I am sharpening up my claws and beak in readiness.

It was not long before the stage was set for one of the most dramatic moments in the history of science, for the British Association for the

Advancement of Science was to meet at Oxford in 1860, and it had been given out that the Bishop of Oxford had determined to "smash" Darwin. The meeting place in the medieval university building was in consequence crowded to suffocation with even the window ledges occupied by university dons keen for the excitement of the contest. By a mere accident and at the last urgent request of his friends Huxley reluctantly agreed to be present, for he rightly believed that an appeal would be made to the emotions and to prejudice, and he feared no good could come from the scientific argument. It was the tremendous success which he here achieved that fully decided him to take up the cudgels for Darwin, and at the sacrifice of being branded as a heretic during much of his lifetime, he was destined to go down to posterity not only as the magnificent protagonist of the doctrine of evolution, but as the redoubtable champion of freedom of thought within the whole realm of science.

Of the encounter at the Oxford meeting there are a number of contemporary accounts, one of which says of the Bishop's address:

> In a light, scoffing tone, florid and fluent, he assured us that there was nothing in the idea of evolution, rock pigeons were what rock pigeons had always been. Then turning to his antagonist with a smiling insolence, he begged to know, was it through his grandfather or his grandmother that he claimed his descent from a monkey.

Huxley was sitting beside the venerable Sir Benjamin Brodie, and at this descent to personalities he struck his hand upon his knee and turning to his neighbor exclaimed, "The Lord hath delivered him into mine hands." Without at all comprehending, Sir Benjamin stared vacantly and the meaning of Huxley's words did not dawn upon him until Huxley had arrived at his famous retort. When the storm of applause which followed the Bishop's address had subsided the president called upon Huxley to reply.

> On this Mr. Huxley slowly and deliberately arose. A slight tall figure, stern and pale, very quiet and very grave, he stood before us and spoke those tremendous words—words which no one seems sure of now, nor, I think, could remember just after they were spoken, for their meaning took away our breath, though it left us in no doubt as to what it was.

There was first a calm scientific discussion of Darwin's theory after which Huxley turned to the Bishop to say:

> I asserted—and I repeat—that a man has no reason to be ashamed of having an ape for his grandfather. If there were an ancestor whom I should feel shame in recalling it would rather be a man—a man of restless and versatile intellect—who, not content with a success in his own sphere of activity, plunges into scientific questions with which he has no real acquaintance, only to obscure them by an aimless rhetoric, and distract the attention of his hearers from the real point at issue by eloquent digressions and skilled appeals to religious prejudice.

"No one doubted his meaning, and the effect was tremendous. One lady fainted and had to be carried out; I, for one," says the chronicler, "jumped out of my seat."

If the emancipation of science from coercion or restraint from without had arrived with the final triumph of the doctrine of evolution, can it be truly said that theories are constructed even in this generation as the result of a process of wholly untrammeled reasoning; or, on the other hand, is it the fact that with the frailties inherent in human nature they still embody elements of weakness which are due either to the deficiencies in training of their authors, to prejudices or bias conditioned upon time or place, or to some other cause?

It is usually considered to be the special function of a president to recount in his address in particular the great triumphs of science, and to touch but lightly, if at all, upon any less encouraging aspects of his science. I propose in the time that remains to me to pursue a somewhat different course, and by the use of examples selected from the field of my own special studies to discuss what may perhaps be called the psychology of theories and the conditions which determine their acceptance.

To some extent it is inevitable that theories should reflect the individuality or the environment of their authors. This is particularly true in the field of natural science, where the laboratory is the world itself, a portion only of which can be brought under the observation of any one individual. Geological processes are different both in degree and in kind according as they are studied under conditions of aridity or of excessive humidity, under tropic heat or polar cold. It is unquestionable that geology having developed as a science in those temperate regions of moderate humidity which have permitted a high degree of civilization, is correspondingly defective, and must be modified if it is to be universal in its scope. The physical geology of deserts has been studied seriously only during the present generation. It is within the last decade only that the attention of geologists has been focused upon the subpolar latitudes, and the geology of the tropical jungles is yet to be written.

To indicate how the peculiar environment, the conditions of the time, and the special activities of the individual have left their impress upon a well-known theory, I may cite the case of Robert Mallet and his centrum theory of earthquakes, a theory which received general acceptation and was orthodox doctrine among earthquake specialists for full half a century. Robert Mallet was educated as a civil engineer, and in 1831 became a partner with his father in the foundry industry at Dublin. During the Crimean War he constructed monster mortars of thirty-six inch caliber which embodied new ideas and were completed in 1854.

Thus becoming interested in ballistics, he made a thorough investigation of the strains developed by explosions in the chambers of guns, and a monograph upon the subject which he published in 1856 brought him general recognition and many honors. A year later, in 1857, occurred the great earthquake in the Basilicata, generally referred to as the "Great Neapolitan Earthquake," since the district was included in the former kingdom of Naples. Believing himself by reason of his studies of explosives to be specially fitted to investigate this disturbance, Mallet applied to the Royal Society for a grant of money, and his request being approved, he visited the Basilicata, and in 1862 in two sumptuous volumes the earthquake was explained as the result of an explosion that had occurred in a cavity beneath the region affected, the damage upon the surface being explained under the laws of transmission of stress such as had applied in his earlier researches upon cannon. No one familiar with these circumstances can reasonably doubt that the trend of his theory was already determined by his life history before his sailing from England. It should be added that through giving to the problem of earthquakes a mathematical treatment, Mallet's study had the effect of removing seismology from the field of geology for the period of nearly half a century, and giving it over to the elasticians.

It has not been altogether uncommon for students of science, and even those of the highest rank, when drawing conclusions, to fail to take proper account of the fact that the observed rates of change, or gradients, perhaps of temperature or pressure, which they have been able to verify for limited distances only, may not be assumed to continue indefinitely without interruption or variation. No less distinguished a physicist than Helmholtz on the basis of the known aero-thermic gradient as determined over Europe to a height of about nine kilometers, declared that the atmosphere could not extend beyond twenty-seven or twenty-eight kilometers from the earth's surface, since the absolute zero of temperature would be reached at that level. Sounding of the atmosphere has since been carried to fully twice the limit fixed by Helmholtz, and has revealed the fact that a few kilometers beyond the limit of exploration when he made his prediction, or at an average altitude of eleven kilometers, the aero-thermic gradient is interrupted and succeeded by practically isothermal conditions above.

Today in reputable treatises one may read in round numbers the supposed temperature at the center of the earth, and based upon what? The geothermic gradient determined for the shell of rock immediately beneath the earth's surface and verified roughly for about one four-thousandth of the entire distance to the earth's center. Can we assume that our yard-stick in this instance is suitable for measurement throughout the

entire radial distance, and is there no possibility of abrupt interruptions such as occur in the temperature gradient of the atmosphere?

William Ferrel, much the most distinguished meteorologist that America has produced, and the one to whom we owe the basic principle upon which modern meteorology is founded, predicted as a corollary to his theory of the winds the existence of whirls about the earth's geographic poles surrounding areas of calm and low atmospheric pressure. As these polar calms and whirls are an important feature of the present theory of atmospheric circulation, it will be profitable to examine briefly their evolution as a study in the psychology of theory. In the preface to his general treatise upon the winds, Ferrel tells us how his attention was first directed to this subject through reading Maury's "Physical Geography of the Sea," the first edition of which appeared in 1855, while the first essay of Ferrel was published in 1856. From Maury Ferrel learned, as he has told us, "that the pressure of the atmosphere is less both at the poles and at the equator of the earth than it is over two belts extending around the globe about the parallels of 30° north and south of the equator." On making reference to Maury we find that upon the basis of recorded observations between the parallels of 40° and 54° south latitude the average barometer reading varies from 29.9 to 29.4 in passing from the lower to the higher latitude. With the gradient obtained from this limited range, Maury has extended the curve as a straight line to the geographic pole through a range of thirty-four degrees of latitude or more than twice the observed distance, and obtained a theoretical reading for the pole of twenty-eight inches of mercury. A similar method applied to the northern polar region has supplied a less marked gradient and a theoretic value for the barometer reading at the northern geographic pole of 29.65 inches of mercury.

Since this theory was promulgated, exploration has been extended to both poles of the earth and has shown that but a short distance beyond the latitudes which limited the data employed by Ferrel, the steadily lowering pressure gives place to a rising barometer in the direction of the poles. Studies of the free atmosphere by means of balloons in the same high latitudes also indicate pretty clearly that no such whirls as Ferrel assumed can exist. Yet so great has been the success of Ferrel's theory as a whole that despite their contradiction by the facts, the polar calms and whirls are still treated in the latest text-books of meteorology.

The polar whirls of Ferrel are by no means a unique example of a large conception in science receiving general support because however carelessly constructed it was an attachment or rider to a still larger theory. The triumph of the larger idea or the prestige of the author due to some other achievement, has by its inertia carried the smaller conception to general acceptance.

So fundamental a theory as that of Laplace to explain the origin of the universe, a theory which has been standard doctrine for more than a century and is only now being replaced as a result of rigidly applied tests, appears never to have been very seriously considered by its author, but was thrown off as a brief appendix or postscript to a general work on astronomy. It has the curious title "Note VII and Last" and Laplace says of it that the hypothesis must be received "with the distrust with which everything should be regarded that is not the result of observation or calculation." Moreover, so far as known, Laplace never subjected the theory to the test of well-known mathematical principles which were involved, although this was his usual habit. The success and general acceptance of the theory seem to have been due to the altogether remarkable prestige of its author as the greatest mathematician since Newton, and as the author of the "Mécanique Céleste," a work which has never been rivaled in its field, and of which it has been said that any one of its twenty-four parts would have made the reputation of a man of science.

Though primarily a theory of the origin of the universe and thus in the realm of astronomy, Laplace's nebular hypothesis left its impress upon geology and particularly upon geophysics, in that it gave continued standing and scientific respectability to the notion that the earth has a liquid interior. It would be somewhat difficult to trace the origin of this belief, which naturally grew up from the observations of volcanic eruptions—no uncommon event in the Grecian Archipelago and in Italy, the regions where science had its beginnings. After the studies of combustion had exploded the notion of "internal fires," the theory took the form which it has retained to our day little affected at first by the proofs of earth rigidity which were brought forward by Kelvin. With little doubt the associated idea of a congealed crust floating upon a liquid interior is based upon the analogy with the winter cover of ice which forms over our lakes and rivers. This analogy supplies, therefore, a striking instance of the influence of climate in giving complexion to a fundamental theory, and the fact that rock, unlike water, is heavier in the solid than in the liquid state, is a very recent discovery. Save for its intimate relation to Laplace's theory, the conception of the liquid core to the earth must have long since been relegated to the limbo of exploded doctrines, to the great benefit of more than one of the physical sciences.

It would be easy to show that well-known scientific theories have embodied fatal defects, in that assumptions of vital importance have been introduced quite unconsciously by their authors. I have believed, and have elsewhere attempted to show, that the Pratt-Hayford theory of isostatic compensation, which assumes for every mountain a necessary defect of mass directly below, and for the column below every depression

of the earth's surface a corresponding excess of mass; that this theory has been set up without due regard to the dominating effect of any hidden masses of unusually high density which may lie near the observing station. This view seems now to have found confirmation in recent studies carried out by the United States Coast and Geodetic Survey. I may perhaps best illustrate what is here meant by the use of an example taken from a related field of study. If one should ascribe the strong magnetic attraction which is exercised by local masses of iron ore in the Northern Peninsula of Michigan to the effect of such an extended system of smaller masses distributed throughout a large district, as might produce the same effect at a given station, the error would be of the same nature as that which must result from ignoring the effect at the gravity stations of any local and very dense masses which may be hidden beneath the surface.

. Does prejudice, either national or racial, ever influence the thinking of men of science? I ask you to look back over the history of the past two and a half years and for the answer examine some of the statements which have been signed by men who were counted among the master scientists of their generation. These sweeping statements were many of them false; and if not known to be by those who subscribed to them, it is clear that an unbiased inquiry must either have revealed the truth or have indicated the necessity of withholding a verdict. This débâcle of science which came at the outbreak of the present war is one not easily to be retrieved.

If I have succeeded in my endeavor, I have shown that scientific theories as they are constructed even today with the aid of all modern equipment and inheritance, may contain fatal elements of weakness though they be promulgated by scientific men of the highest rank and attainments. Fortunately the student of science today enjoys an independence which was never vouchsafed him in the past, when the learner was by the conditions under which he studied an advocate of the doctrines of his master. There are today no dictators in science such as were Werner in Germany, de Beaumont in France, Murchison in England, or Agassiz, the "pope of American science." For what he accepts and teaches the student of science is today responsible, and it devolves upon him not merely to examine each theory as regards its inherent plausibility and the degree to which it has been confirmed, but to inquire also into the human and other factors which have entered into it or which have accounted for its acceptance into the body of doctrine of science.

It has seemed to me that the excessive stress which in our science training we now lay upon the careful balancing of evidence, has in a measure taken away our capacity for making decisions. The cult of being open-minded has been elevated into a fetich, with the result that

the really vital considerations are often hopelessly entangled with non-essentials. A little reflection must show that upon the principle of chances the weight of evidence in the case of but few problems can be evenly balanced; but a clever exaggeration of the non-essentials seldom fails to raise serious doubts in the minds of a considerable proportion of those considered qualified to reach a decision. Why, if this be not so, have so many of our highly trained scholars failed to see that the events which are now transpiring have long been clearly foreshadowed, and were inevitable results of observed conditions in a world controlled by natural laws. This is due to a lack of vision—of prescience—which above all is dependent upon first clearing away from a question the rubbish which has accumulated about it, and then focusing the attention unerringly upon the heart of the problem.

Lack of vision largely explains the great inertia of science which causes the retention of useless or harmful theories long after their inadequacy or falsity has been exposed, and this inertia is greatly aggravated by potent accessory influences. Any successful theory which occupies a basic position in science, is sure to be built upon as a foundation for other theories, and these are likely to crumble with its collapse. Much money and labor are now invested in treatises and popular works, the income from which becomes seriously affected whenever their reliability is brought into question. The ultra-conservative attitude of scientists which results from these and other causes is as obvious as it is deplorable.

As we look back over the past and, studying the advances of science, mark off upon the way the stations at each of which a new horizon has opened, it is easy to see that the successive marches, like the halts between, have been far too long. The attempt to reproduce from each station the entire panorama of the horizon has led to a sketchiness and an inaccuracy in the depicting of all remoter portions of the field, which might have been avoided had the viewpoint been promptly moved forward so soon as the nature of the nearer terrane had become firmly established. My appeal is, therefore, for an individual study of those theories of science with which each worker is concerned, and for an early decision upon their availability whenever a judgment is warranted. Accepted, if necessary, as working hypotheses to be rigidly tested by observation and experiment, the new ideas are infinitely to be preferred to those theories which have been found wanting under the tests either of experiment or of searching observation.

It might perhaps be asserted that the picture which I have drawn of the past and present of scientific theories is one not calculated to cause entire satisfaction; and I could hardly deny the truth of the assertion; but when, I would ask, has either an institution or an individual been

other than benefited through a searching self-examination? Even the shock to our self-pride which came with the revelations of this bellum period is not fraught with permanent disaster. Since the condition existed, it is far better that we should know it, and so far as may be possible provide against its recurrence in the future.

The encouraging feature of our entire survey is the evidence which it shows of a steady evolution toward better conditions; for no one can truthfully deny that the scientific world is today in a far better position than it has ever occupied in the past; and the outlook for the future is so much the more encouraging.

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# ZOOLOGY.

2

# TERRARIA AND BALANCED AQUARIA IN THE LABORATORY.

ELIZABETH L. THOMPSON.

It is not the aim of this report to set forth a mass of new material. It is, rather, an attempt to gather together into a condensed and usable form much scattered data on the subject of terraria and aquaria, including the methods which have actually been tried out by the writer, and to emphasize the value of this somewhat neglected source of information in laboratory work. The needs for such a compilation and for simple directions became apparent in an attempt to introduce this subject into class work in a limited time. It was found that the books available for this work contained so much extraneous material and so many non-essential details that they were almost useless for directive work.

The value of the aquarium as a sort of "Zoological Garden" for aquatic animals has long been recognized by museums for demonstration purposes but not fully appreciated from the educational point of view in laboratories and schools. The ease of construction and maintenance of both the balanced aquarium and the terrarium puts them within the reach of every laboratory, every school and even every home. For the aquarium running water is not necessary. The tank should not be considered a cage, but rather a limited "habitat" for the animals which it contains and this habitat should be made as nearly like the natural habitat of these animals as possible. This attempt to reconstruct the natural environment will necessitate the introduction of water plants, a medium of sand and gravel for their roots and conditions of light and temperature suitable for their growth. The plants and animals each contribute certain elements necessary to the other, the "balance" works out automatically and little further attention is required.

The aquarium in the laboratory has almost unlimited possibilities for the study of aquatic life and the materials for its construction and population are usually readily available. A medium sized tank, that is, one containing from two to three gallons of water, or a still smaller tank, rectangular, square or cylindrical (never globe shaped) will be found most satisfactory. It should be of white glass, not green. Battery jars of various sizes or even fruit jars of the straight sided type make excellent tanks. The cylindrical jar has the disadvantage of making the animals and plants within appear somewhat distorted when viewed

through the glass, yet this is not marked enough to exclude them from use. The size must of course depend to some extent upon the storing place for the tank and the number and size of the animals which it must contain. In general, much more pleasure as well as instruction can be derived from several small aquaria than from one large one, not only because the small tanks are more easily cared for, but also because of the greater variety of animal life thus afforded for observation and study. Animals must be more or less segregated according to their size and habits. The number of species possible in a single aquarium is not necessarily great.

The balanced aquarium, strictly speaking, is just what the name implies, that is, an aquarium in which the plant and animal life is so balanced that aeration of the water takes place automatically and the food cycle is complete. In the ordinary small aquarium, however, it will be found advisable to modify the balance by the introduction of food for some of the larger animals. The plant and animal life is mutually beneficial and artificial aeration such as running water or compressed air is unnecessary. Thoroughly washed sand should be placed on the floor to the depth of an inch at least, and on top of this a layer of fine and medium sized gravel, also thoroughly washed, of approximately the same depth. The depth of the sand and gravel is important since they form the rooting place for the plant life, and there is frequently a greater tendency to use too little rather than too much. Both sand and gravel, if not easily obtained elsewhere, can usually be found where cement work is being done or has been done recently.

Water plants suitable for an aquarium can usually be found until late in the fall in almost any small river, creek, ditch, small lake or permanent pond. They may also be purchased from dealers carrying goldfish and aquarium or fish supplies. The more common plants* for the region about Ann Arbor, Michigan, are—

Hornwort *(Ceratophyllum demersum)*. Eggeling and Ehrenberg, pp. 35 and 40.

Crystal worts *(Riccia fluitans* and *R. natans)*. Bateman and Bennett, pp. 90-1. Eggeling and Ehrenberg, p. 91.

Canadian waterweed *(Elodea canadensis)*. Eggeling and Ehrenberg, pp. 43-4.

Small duckweed *(Lemna minor)*. Bateman and Bennett, p. 89, Eggeling and Ehrenberg, p. 86.

Three-leaved duckweed *(Lemna trisulca)*. Bateman and Bennet, p. 89, Eggeling and Ehrenberg, p. 87.

Water milfoil or Thousand-leaf *(Myriophyllum heterophyllum)*. Eggeling and Ehrenberg, p. 70.

*The writer is indebted to Dr. J. B. Pollock for assistance in preparing the list of plants.

Tape-grass *(Valis neria)*. Eggeling and Ehrenberg, pp. 46 and 48.

Mermaid weed *(Proserpinaca plustris)*. Eggeling and Ehrenberg, pp. 35 and 56.

Water crow-foot *(Ranunculus aquatilis)*. Eggeling and Ehrenberg, p. 62.

Pond-weed *(Potamogeton perfoliatus)*. Eggeling and Ehrenberg, p. 55.

The roots of the plants should be brought in when possible, but it will be found that stems carefully planted will soon root and thrive in the new location. No rule can be given as to the exact number of plants to introduce into an aquarium of a certain size, but it is an observed fact that there is greater danger of planting too few than too many. Where stems alone are used it will be found necessary to weight down the lower ends. This may be done very satisfactorily by means of small strips of lead a quarter of an inch or less in width. The strips should be bent rather loosely about the base of the stems and buried with them well down in the sand. Several stems or plant slips may be planted together, weighted down by the same piece of lead. Crowding in this way, however, should be avoided as there is a greater tendency for the stems to decay. The plants should be thoroughly washed, preferably in running water and may even profitably be sterilized before being introduced into the aquarium. Osburn (1914) suggests immersing them for ten to fifteen minutes in a solution of creolin (two teaspoonfuls to a gallon of water). This washing and sterilizing process will not only get rid of much dirt but will also lessen the danger of undesirable algae and many forms of parasitic life.

After the plants have been arranged the aquarium is ready for water. For this purpose clean river, creek or pond water is best, but moderately hard tap-water (not chemically treated) or rain water (not cistern) may be used. The water should be poured in gently or if tap-water is used it should be allowed to flow slowly through a tube in such a way as not to disturb the plants. If the sand and gravel have been thoroughly washed, the water should not be roiled by this process. The tank should be filled to within two to four or five inches (depending somewhat upon size) of the top. Debris collected at the surface may be skimmed off with a spoon or the tank may be allowed to overflow and the surplus water either dipped or siphoned out. Floating plants such as "duck-weed" should now be introduced. The tank should be kept covered to prevent evaporation and the entrance of dust; for this purpose a glass cover is better than any other because of its advantage for observation purposes. It should be placed where it will receive plenty of light—preferably but not necessarily, north light. Bright sunlight should be avoided and a temperature ranging from 50 to 70 degrees Fahrenheit (Osborn, 1914) is desirable. It is better to leave the aquarium undis-

turbed for a few days before introducing the animals. This allows the plants to become adjusted to the new conditions and the water becomes thoroughly aerated.

Too many animals should not be introduced. The amateur aquarist usually overcrowds. A general rule for fish offered by Page (1898) is three inches of fish to a half gallon of water, Osburn (1914) is even more parsimonious and suggests one inch of fish, not including the tail, to one gallon of water. The animals should be carefully selected according to size and habits. For this region the black-nosed dace *(Rhinichthys atronasus)* will be found very satisfactory. This species is easy to find, apparently hardy and thrives on prepared fish food. Sunfish or pumpkinseeds *(Eupomotis gibbosus)* and bluegills *(Lepomis pallidus)* require meat for food and if not kept well fed will attack both fish and tadpoles. The miller's thumb *(Cottus ictalops)* is a shallow water species and will not live long in the ordinary aquarium. Tadpoles, although good scavengers, root up the plants and keep the water more or less roiled. They should be introduced sparingly. Snails are almost a necessity in the aquarium since they are not only good scavengers but also aid materially in keeping the growth of undesirable algae under control. Physa and Planorbis will be found especially satisfactory. They breed readily in the tanks and their eggs and young furnish a limited amount of food for the fish. A dozen or more will be found valuable in every aquarium. Water bugs will prove interesting but they should be carefully identified before putting them into the tank as many of them are carnivorous and will quickly attack the other animals present. A large number of insects belonging to several orders pass through an aquatic larval stage; some of these are carnivorous while others are vegetarians (Miall, 1895); the necessity of a certain amount of identification is obvious. *Hydra viridis* will, under ordinary circumstances, live well and multiply quite rapidly in the balanced aquarium. They are apparently undisturbed by fish and snails and seem to require no food, possibly due to the symbiotic algae which they contain, and the micro-organisms in the water. Colonies of Vorticella are frequently introduced with snails. They multiply and spread rapidly and form an interesting subject of study. The fresh water sponge (Spongilla) may also be readily grown from gemmules and although more or less disturbed by fish and especially by tadpoles, may attain a fair size. This form will be found of especial interest because it is so frequently passed over unobserved in field work that it is seldom brought into the laboratory.

It will thus be seen that a great variety of animals may be introduced if care is used in selecting them. They soon accommodate themselves

to their new environment and may be studied under approximately natural conditions. Of the animals suggested fish and tadpoles are the only ones that must be fed. Prepared fish food and very small bits of uncooked meat will be found sufficient for them. Care should be taken always to remove uneaten pieces of meat as these macerate rapidly and pollute the water. As plants become uprooted, as will surely be the case if tadpoles are in the tank, they should carefully be replanted because they are not only necessary to the "balance" of the aquarium but if allowed to float will soon decay and become a source of contamination.

If proper precautions and reasonable care are observed, the balance between plant and animal life will soon be obtained. The growing plants function in the oxidation of the water and the animals contribute carbondioxide and nitrogen necessary for plant growth, the balance becomes established with the exception of the partial food supply, and when once obtained the aquarium requires almost no further attention and becomes a valuable demonstration of the interdependence of plant and animal life.

Should it become necessary for any reason to change the water or to remove part of it to facilitate moving the tank, it can readily be done by carefully dipping the water out or by using a small rubber tube as a siphon. This should never be done if avoidable, particularly if the tank contains Hydra, as many of those adhering to the sides will be killed. They may be kept alive for a brief period while water is being changed, if they are not allowed to dry.

The terrarium is equally valuable in the laboratory and when properly constructed requires little if any more care than the aquarium. The type of terrarium suited to salamanders, frogs and animals requiring similar environments only, will be considered here. The same types of tanks may be used as for the aquaria. If a sufficient quantity of gravel, that is, a layer at least an inch thick is used for the foundation, a drainage outlet will be found unnecessary. The gravel may or may not be followed by a layer of sand, but a layer of mixed leaf-mold and soil must be used as a rooting place for the moss, ferns and other plants introduced. Here also care must be exercised in the selection of animals, although there is less danger from crowding than in the case of the aquarium. Small frogs will be eaten by large ones; snakes, even small ones, are more or less unsatisfactory when kept with other animals and if collected should have a tank or cage separate from them; terrestial snails are easily obtained and live harmoniously together; small salamander, particularly *Diemyctylus viridescens,* make very satisfactory inmates, the Ambystomas, however, should be in a separate terrarium where they

may either be supplied with suitable places for hiding, such as small pieces of curved tiling buried under moss, or where they may be allowed to burrow. Earthworms thrive in the leaf-mold and will aid in furnishing food for the frogs and salamanders during the winter months.

The terrarium may be made very attractive by the introduction of plants found in damp woodland associations. Mosses of various kinds and liverworts such as Marchantia form a natural carpet. Hepaticas and similar plants brought into the laboratory in the late autumn will blossom during the winter. Small ferns and pitcher plants and many other plants will grow well in this environment. The suggestions made in regard to light and temperature for the aquarium will also apply to the terrarium. The ground must be kept damp and the tank well covered to prevent evaporation.

The feeding of the animals is a greater problem than in the case of the aquarium. Lettuce will be found very satisfactory for the snails and, although they are generally considered herbivorous, it is interesting to see how soon they will gather around a small piece of uncooked meat placed in the terrarium. The snails must be kept well fed in order to keep them from attacking the plants. Frogs will eat earth worms and occasionally can be induced to eat uncooked meat cut in worm-like pieces and kept in motion before them. The salamanders will eat both earthworms and meat readily. The frogs and salamanders will not need to be fed oftener than two or three times a week, the interval depending somewhat upon the temperature at which they are kept. Small snakes sometimes kept in terraria will usually eat earthworms and will attack small frogs such as the cricket frog *(Acris gryllus)* and the spring peeper *(Hyla pickeringii)*. These small frogs will also be eaten by the larger salamanders (the Ambystomas).

Bateman (1897) gives rather extensive directions for the construction of various types of terraria, while Bateman and Bennett (1890) give valuable directions for the construction of glass and metal tanks suitable for aquaria. Many books on the subject give lists of implements necessary in the care of the aquarium; however a pair of forceps, seven or eight inches long, either metal or wood, a long glass tube with a rubber bulb on the end, several feet of 5 or 6 mm. rubber hose to use in siphoning and a small dip-net will be found sufficient for ordinary requirements.

Terraria and balanced aquaria made up by students or teachers in the fall will provide interesting material for observational work during the winter months when living material is hard to obtain. A few types only of those available have been mentioned here; no attempt has been

made to even enumerate the probable microscopic forms present in such tanks. Students coming in contact with such demonstrations unconsciously become familiar with these types of animals and the environment in which they live. An interest in living animals and their habits is aroused apart from the routine of laboratory work and such an interest may well serve to carry students farther along in this field of study.

Literature cited: Bateman, G. C., 1897. The Vivarium. London, Eng. Bateman and Bennett, 1890. The Book of Aquaria. London, Eng. Eggeling and Ehrenberg, 1912. The Freshwater Aquarium. New York. Miall, L. C., 1895. The Natural History of Aquatic Insects. London, Eng. Osburn, R. C., 1914. The Care of Home Aquaria. New York Zoological Society, New York. Page, C. N., 1898. Aquaria. Des Moines, Iowa.

# THE OCCURRENCE OF A SUPERNUMERARY OCELLUS IN PLANARIA MACULATA.

BERTRAM G. SMITH.

In preparing for class use some whole mounts of Planaria, I was surprised to find one with a well-developed supernumerary ocellus, as pictured in Plate I, Figures 1 and 2. This specimen belonged to a lot collected during the summer of 1910 in Monona Lake, Wisconsin. These planarians were unusually large and abundant, and when captured appeared to be in a very thriving condition.

The chief point of interest in such a variation is of course to determine whether it is a mere abnormality of development, or a heritable variation of germinal origin—the kind of variation which is of significance for organic evolution. It is unfortunate that the peculiarity was not observed while the animal was in the living condition, in order that it might be studied by breeding experiments; but in the absence of data from this source the following considerations seem sufficient to settle the question.

If the supernumerary ocellus were an abnormality due to some accident of development, it would mean that a portion of the anlage of an ordinary eye had been split off, leaving the original eye reduced in size. But in this specimen both of the ordinary eyes are of the usual size, and normal in all respects. Furthermore, the supernumerary ocellus is in the exact position of a member of the second pair in animals in which the paired ocelli are metamerically repeated (e. g., a leech or a seaworm). The chances against this position being attained through some accident of development are enormous. We must conclude, I think, that this variation is of germinal origin. One might also call attention to the obvious fact that the peculiarity is not one due to a recombination of characters possessed by the parents, but is something new to the race—the sort of variation one would seek in looking for the raw materials which make evolutionary advance possible. It is a mutation in the strict sense of the word.

19th Mich. Acad. Sci. Rept., 1917.

A further point of interest is that we have here a meristic variation occurring in a non-metameric animal belonging to the group which by common consent is regarded as ancestral to the metameric worms.

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LEGENDS.

Plate I. Figure 1. Photomicrograph of the anterior end of a planarian with supernumerary ocellus.

Figure 2. Drawing explanatory of Fig.1. (X 60.)

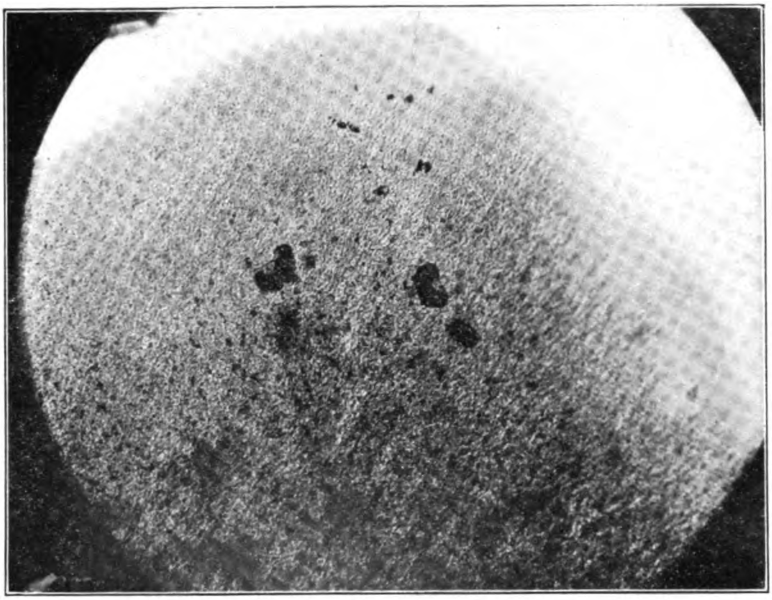

Figure 1.

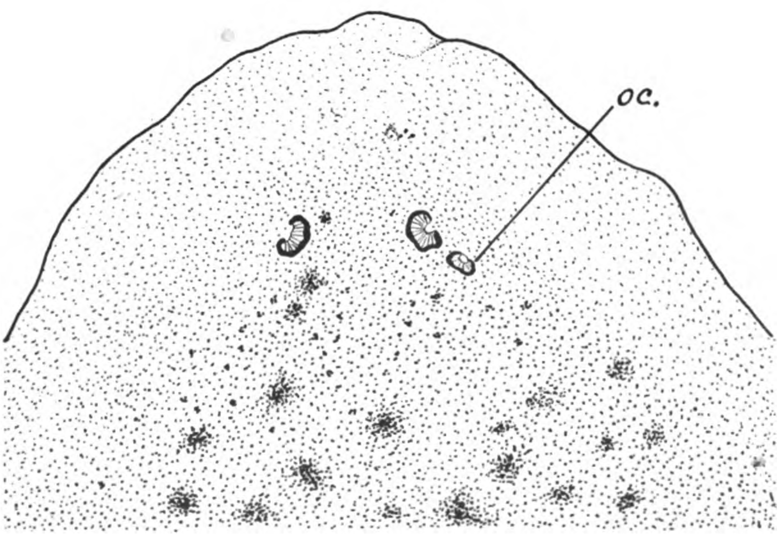


Figure 2.

# AMPHIBIANS AND REPTILES OF THE DOUGLAS LAKE (MICHIGAN) REGION.

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*Introduction.*

The Douglas Lake region as here designated includes portions of both Emmet and Cheboygan Counties, Michigan, lying between 84° 30′ and 84° 40′ W. and 45° 30′ and 45° 40′ N. This area is in the extreme northern part of the southern peninsula of Michigan although still an interior unit, 15 to 20 miles inland from Lake Michigan on the west, the Straits of Mackinac on the north and Lake Huron on the east. In general this part of the state is covered with glacial deposits and the soil is very sandy. The terrestrial vegetation includes a large amount of aspen and associated plants in the cut-over and burned-over areas formerly occupied by forest, some virgin forest and some second-growth forest. In the immediate vicinity of streams, lakes and bogs are various transitional series of plants connecting the terrestrial and aquatic plant associations.

The collections on which this report is based were made during the months of July and August, 1913 to 1916 inclusive. A representative series of the species found has been deposited in the Museum of the University of Colorado. The records of species taken in the vicinity of Cecil, Emmet County, on the shore of Lake Michigan, have been added to the annotated list.

## ANNOTATED LIST.

Of the 24 species recorded in the following annotated list, six have not been reported previously from the Douglas Lake region. These six species are *Hyla pickeringii, Eumeces quinquilineatus, Storeria occipitomaculata, Thamnophis sauritus, Chelydra serpentina* and *Terrapene carolina.* Fourteen of the other 18 species were listed from the Douglas Lake region by Ruthven (1911 b, p. 115) and the remaining four species, together with the 14 reported by Ruthven (l.c.), were recorded by Ruthven, Thompson and Thompson (1912).

### AMPHIBIA.

1. *Necturus maculosus* Rafinesque. Mud Puppy. Only three individuals of this species were taken alive. Two of these were collected in shallow water near Grapevine Point, Douglas Lake; one, floating at the surface although still able to move when disturbed, July 20, 1914, and the other in a drag-seine, August 10, 1915. Both animals died soon after they were captured. The third individual was taken near Bryant's Dock, Douglas Lake, August 15, 1915, and seemed in very good condition, living in the Biological Station aquarium for several days. A few dead, beached specimens of this species were found each year on the shore of Douglas Lake. The largest Necturus from the Douglas Lake region examined was 250 mm. in length.

2. *Ambystoma jeffersoniamum* (Green). Jefferson's Salamander. Seven specimens of this salamander were taken during the four summers. All of these animals were found under rotten hemlock logs in the hardwoods near North Fishtail Bay, Douglas Lake.

3. *Plethodon erythronotus* (Green). Red-backed Salamander. This salamander was very abundant under and in rotten logs in the hardwoods, and was frequently found under logs in the damper parts of the aspen country. Eggs of this species were collected as early as July 5 (1914) and as late as August 18 (1915). Most of the eggs were laid before the 10th of August, as nearly all of the eggs found after that time contained well-developed embryos. Adult salamanders of this species were collected at several stations in both Emmet and Cheboygan Counties and near Cecil, Emmet County.

4. *Diemictylus viridescens* Rafinesque. Green Newt. A common amphibian in the lily ponds of Lancaster Lake, Douglas Lake and Bessey Creek, a small stream connecting these two lakes. This newt was very abundant in the beach pools on Sedgepoint, Douglas Lake, during the summers of 1914 and 1915. Eggs of the newt were collected several times in July, 1915, and on July 16, 1916, and larvae less than 10 mm. in length, during each of the four summers before the first of August. Specimens in the "miniatus" phase of coloring were collected under beached wood and debris near the lily pond in North Fishtail Bay, Douglas Lake.

5. *Bufo americanus* LeConte. Common Toad. Common in the region. Large adults were seen frequently in the Thuja bogs near Douglas Lake and on the Jackson and Tindle holdings in Emmet County. Small individuals were often very abundant in the vicinity of beach

pools. Several adults were taken on the banks of Carp River, Cecil, Emmet County, and on the shore of Lake Michigan east of Cecil, August 19, 1916.

6. *Hyla versicolor* LeConte. Common Tree Frog. Rather common in the region. From three to a dozen specimens were taken each of the four summers near the Biological Station.

7. *Hyla pickeringii* Holbrook. Spring Peeper. The writer has seen only three specimens of this frog collected in the Douglas Lake region, two of which were taken near the road through Reese's Bog and the third in the hardwoods near Reese's Bog, 1914.

8. *Acris gryllus* LeConte. Cricket Frog. Very abundant in the lowland near the west side of Reese's Bog in 1913. A few specimens were taken in the same locality in 1915.

9. *Rana pipiens* Shreber. Leopard Frog. The most abundant amphibian in the region. Very common near lakes and streams and not infrequently found in the damper parts of the aspen country. Also taken at Cecil, Emmet County, August 19, 1916.

10. *Rana clamitans* Latrielle. Green Frog. A common species in swampy areas adjoining Lancaster Lake, in the oxbows on Maple River west of Bryant's Landing, and in the vegetation near beach pools on Sedgepoint, Douglas Lake. This frog was usually found in the shaded areas near bogs and small streams, and was very abundant in the outskirts of the large Thuja bog on West Maple River. Several specimens were taken on the banks of Carp River at Cecil and in a large beach pool on the shore of Lake Michigan near Cecil, Emmet County, August 19, 1916.

11. *Rana cantabrigensis* Baird. Wood Frog. An abundant species in the transitional vegetation between aquatic and forest habitats. The wood frog was found regularly in the outskirts of Thuja bogs near Lancaster Lake, Douglas Lake and West Maple River. Many individuals of this species were seen in similar situations along the shore of Lake Michigan between Cecil and Mackinaw City, August 19, 1916.

12. *Rana catesbeana* Shaw. Common Bullfrog. This species was very abundant in the lily ponds and along the shaded banks of Bessey Creek in 1913. It was taken in swampy areas near Lancaster Lake, Munro Lake and Douglas Lake, on East Maple River, and in the Thuja bog on West Maple River. Two specimens were collected at Cecil, Emmet County, August 19, 1916. Large bullfrogs were less numerous each successive summer and even small bullfrogs were scarce during the

summer of 1916. The use of this frog for food may in a measure account for this change in abundance.

## REPTILIA.

13. *Eumeces quinquilineatus* (Linnaeus). Blue-tailed Skink. One specimen of this lizard was collected on the sand near Burt Lake in the vicinity of the Burt Lake hardwoods, July 6, 1913. This individual measured 120 mm. in length. No other specimens of the skink have been taken in the Douglas Lake region. This record, although based on a single specimen, is of particular interest as it moves the known range of this lizard in Michigan over a degree north. Ruthven (1911 a, p. 268) recorded this species from Sand Point, Saginaw Bay, Huron County, and Thompson (1915, p. 4), from near East Lake, Manistee County.

14. *Storeria occipitomaculata* (Storer). Red-bellied Snake. Found in damp woodland and less frequently in aspens under fallen timber, near both Lancaster and Douglas Lakes. From five to ten individuals were collected each summer. Three specimens of this snake were secured at Cecil, Emmet County, August 19, 1916.

15. *Heterodon platyrhinos* Latrielle. Hog-nosed Snake. This snake was fairly common throughout the region but was seen most frequently in the sand and aspen country within a mile of water. The hog-nosed snake is evidently rather common in both Emmet and Cheboygan Counties as many farmers spoke of the "Spreading Adder" when questioned concerning the snakes of the region. The largest specimen measured by the writer was 35 inches in length. Most of the specimens of the hog-nosed snake taken were in the black phase of coloring.

16. *Natrix sipedon* (Linnaeus). Watersnake. Excepting the common gartersnake, the watersnake was the most common reptile of the region. It was found, however, only in aquatic and semi-aquatic habitats. Several large specimens have been taken in the immediate vicinity of Douglas Lake and Bessey Creek. Three of these measured 37, 39 and 40 inches respectively.

17. *Liopeltis vernalis* (DeKay). Grass Snake. This snake was rare during the summer of 1913. Several specimens were taken during the summers of 1914 and 1915, and nine were collected in 1916. This snake was taken in the hardwoods on Burt Lake, near Sedge Pool on Douglas Lake, near Bryant's Bog and on Lancaster Lake. On August

18, 1914, a set of six eggs of the grass snake were found in the grass near an abandoned log pile south of Douglas Lake. These eggs hatched two days later.

18. *Diadophis punctata* (Linnaeus). Ring-necked Snake. Rare in the Douglas Lake region. The writer has seen only four snakes of this species collected in this region, all of which were found under fallen timber north of North Fishtail Bay, Douglas Lake, during the summers of 1914 and 1915. One specimen of the ring-necked snake was collected by Dr. F. C. Gates and Dr. J. H. Ehlers between Cecil and Great Stone Bay near the shore of Lake Michigan, August 19, 1916.

19. *Lampropeltis doliatus triangulus* (Boie). King Snake. A fairly common snake in the drier parts of the aspen country near Douglas and Burt Lakes. One specimen was found between Lancaster and Mud Lakes, Cheboygan County, in August, 1916. Most of the individuals of this species examined were rather large, ranging from 18 to 34 inches in length.

20. *Thamnophis sauritus* (Linnaeus). Ribbon Snake. A common snake in the Chamaedaphne bogs and near sedge pools, often locally very abundant or very scarce. Prof. A. C. Conger collected several ribbon snakes in the vicinity of Douglas Lake during 1915 and 1916 which measured 30 inches or more in length. This snake was taken at Cecil, Emmet County, August 19, 1916.

21. *Thamnophis sirtalis* (Linnaeus). Common Gartersnake. The most abundant and most noticeable reptile of the region. Also taken at Cecil, Emmet County. Several of the many specimens collected in the Douglas Lake region showed the conspicuous red bars between the scales on the sides of the body which are so characteristic of the western species. *Thamnophis parietalis* (Say).

22. *Chelydra serpentina* (Linnaeus). Snapping Turtle. One specimen of this turtle was captured on the west shore of Douglas Lake in August, 1913, and a second, near Bessey Creek, in July, 1915. Several of the residents of the vicinity told the writer that the "Snapper" was common in Douglas Lake 20 years ago. It is not common in this region at present.

23. *Chrysemys cinerea* (Bonaterre). Western Painted Turtle. Common in the lily ponds of Douglas, Munro and Lancaster Lakes. This turtle was collected occasionally in Bessey Creek and in the oxbows on Maple River. Eggs of this species were dug from the soft sand near

the edges of lily ponds during each of the four summers. A female of this species laid three eggs August 17, 1916, in the sand of her cage at the Biological Station.

24. *Terrapene carolina* (Linnaeus). Box Turtle. One specimen from the sand west of the Burt Lake hardwoods, collected August, 1918. This record is from the most northern locality for this species in Michigan.

## SUMMARY OF SPECIES.

| | | |
|---|---|---|
| Amphibia | | 12 |
| Proteidae | 1 | |
| Ambystomidae | 1 | |
| Plethodontidae | 1 | |
| Salamandridae | 1 | |
| Bufonidae | 1 | |
| Hylidae | 3 | |
| Ranidae | 4 | |
| Reptilia | | 12 |
| Scincidae | 1 | |
| Colubridae | 8 | |
| Chelydridae | 1 | |
| Testudinidae | 2 | |

## COMPOSITION OF THE DOUGLAS LAKE FAUNA.

The composition of the herpetological fauna of the Douglas Lake region may be seen from the following table which compares the intrastate distribution of the several species known to occur in the Northern Peninsula of Michigan, the Douglas Lake region and the Saginaw Bay region. This table (table 1) is compiled from Ruthven (1911 a), Ruthven, Thompson and Thompson (1912), Thompson and Thompson (1912), Evans (1915) and Gaige (1915), together with the annotated list of the present paper. All of the species reported from the three regions mentioned above are included in this table regardless of their occurrence in the Douglas Lake region. In order to contrast the northern and southern range of the species listed, the presence or absence of each species in southern Michigan, i. e., south of the Grand and Saginaw Rivers, is indicated in the first column.

Table 1.

| | South of Saginaw-Grand Line | Saginaw Bay Region | Douglas Lake Region | Northern Peninsula |
|---|---|---|---|---|
| Necturus maculosus | * | * | * | * |
| Ambystoma jeffersonianum | * | * | * | * |
| Plethodon erythronotus | * | * | * | * |
| Hemidactylium scutatum | * | | | * |
| Diemictylus viridescens | * | * | * | * |
| Bufo americanus | * | * | * | * |
| Hyla versicolor | * | * | * | * |
| Hyla pickeringii | * | * | * | * |
| Acris gryllus | * | | * | |
| Chorophilus nigritus | * | * | | * |
| Rana pipiens | * | * | * | * |
| Rana clamitans | * | * | * | * |
| Rana cantabrigensis | * | * | * | * |
| Rana septentrionalis | | | | * |
| Rana catesbeana | * | * | * | * |
| Total 15 | 14 | 12 | 12 | 14 |
| Eumeces quinquilineatus | * | * | * | |
| Storeria dekayi | * | * | | |
| Storeria occipitomaculata | * | * | * | * |
| Heterodon platyrhinos | * | * | * | |
| Elaphe vulpinus | * | * | | * |
| Natrix sipedon | * | * | * | * |
| Liopeltis vernalis | * | * | * | * |
| Diadophis punctata | * | | * | * |
| Lampropeltis doliatus triangulus | * | * | * | |
| Thamnophis sauritus | * | * | * | |
| Thamnophis butlerii | * | * | | |
| Thamnophis sirtalis | * | * | * | * |
| Sistrurus catenatus | * | * | | |
| Chelydra serpentina | * | * | * | * |
| Chrysemys cinerea | * | * | * | |
| Chrysemys bellii | | | | * |
| Terrapene carolina | * | | * | |
| Clemmys insculpta | | | | * |
| Total 18 | 16 | 14 | 12 | 9 |

It can be seen in table 1 that the amphibian and reptilian species have different distributional relations, the amphibia in general, ranging farther north. This grouping of species has been noted in other studies of the distribution of amphibians and reptiles, and Ruthven (1911 a, p. 257) states in discussing the Saginaw Bay fauna that, "in the case of amphibians and reptiles, however, we do not, as in the case of mammals and birds, have many other forms coming into the fauna from the northward, and the explanation is that these groups are preeminently tropical and are in this region reaching the outskirts of their range. This is less

true of the amphibians than of the reptiles, for the former have a greater capacity for enduring the cold."

These statements of distribution are also applicable to the Douglas Lake fauna, although the capacity to endure cold may not be the only difference between the amphibian and reptilian species which should be considered in this connection. The amphibian faunas of the Northern Peninsula, the Douglas Lake region and the Saginaw Bay region are essentially the same, and excepting one species, the mink frog, *Rana septentrionalis,* all of the species of amphibia known to occur in these three regions are found south of the Saginaw-Grand line. The Douglas Lake region marks the northern limit of the known distribution in Michigan of but a single amphibian species, *Acris gryllus,* the cricket frog, although there are species whose known northern limit is south of this region. The reptilian faunas of the three regions compared are not the same, the fauna of the Douglas Lake region including more species than the fauna of the Northern Peninsula and less than that of the Saginaw Bay region. Six of the 12 species of reptiles found in the Douglas Lake region, at present are not known to occur north of the Douglas Lake region in Michigan. These species are *Eumeces quinquilineatus, Heterodon platyrhinos, Lampropeltis doliatus triangulus, Thamnophis sauritus, Chrysemys cinerea* and *Terrapene carolina.*

Comparing the amphibian and reptilian faunas of the Douglas Lake region with those of Michigan as a whole, as regards specific composition, the amphibian fauna of the Douglas Lake region will be found richer than its reptilian fauna, both in relative number of species and kinds of species. The amphibian fauna of this region includes about two-thirds of the species of amphibians reported from Michigan and representatives of each amphibian family found in the state. The reptilian fauna of the Douglas Lake region, however, includes less than half of the reptilian species known to occur in Michigan, and is essentially ophidian, two of the three turtles, *Chelydra serpentina* and *Terrapene carolina,* and the single lizard, *Eumeces quinquilineatus* being rare in the region. Of the 16 species of snakes reported from Michigan (Ruthven, Thompson and Thompson, 1912), 12 are found in the Saginaw Bay region, eight in the Douglas Lake region and six in the Northern Peninsula. This scant snake fauna of the Douglas Lake region is composed of small, or at most moderately large species, feeding almost entirely upon fishes, amphibian and small invertebrates. Two types of snakes are conspicuously wanting among these eight species, namely, species feeding

regularly upon mammals and birds, and species of large size. The king snake, *Lampropeltis doliatus triangulus,* is the only snake found in this region, reported to feed upon mammals and birds regularly (Ditmars, 1908, p. 344; Ruthven, Thompson and Thompson, 1912, p, 111); and the king snake and the watersnake are the only ophidian species which attain the length of 40 inches or more. Large species like the black snake, *Bascanion constrictor,* are not included in the Douglas Lake fauna.

The entire series of amphibians and reptiles known to occur in the Douglas Lake region may be summarized as one of rather few species, the reptilian members of which are, in several cases at least, very near the northern limit of their range.

## LOCAL DISTRIBUTION AND INTERRELATION OF SPECIES.

In the following tables (2, 3 and 4) the distribution of the several species of amphibians and reptiles of the Douglas Lake fauna is considered with reference to the habitats in which these animals were found. Some of the habitats have been named according to the conspicuous plant species of the plant association or assemblage occupying the habitat so designated, for although the amphibians and reptiles considered do not feed upon plants to any extent, certain rather definite relations were found between the local distribution of these animals and that of the several plant assemblages. In the tables (see table 2) the relative abundance of each species as ascertained by repeated collecting in each habitat is indicated by letters. The distribution of each species in the region is shown by the series of habitats in which it occurs. It is to be remembered that these tables give the local distribution of the fauna during the months of July and August only, that is the summer aspect of the fauna.

Reviewing the local distribution and interrelations of the amphibians and reptiles of this fauna two grades of species, primary and secondary, based upon the relative abundance of the individuals of the several species were recognized. The various species were grouped into three ecological series according to the habitat preferences of the seven primary amphibian species, *Diemictylus viridescens, Rana pipiens, Rana cantabrigensis, Rana clamitans, Rana catesbeana, Bufo americanus* and *Plethodon erythronotus.* This grouping was followed because it was found that most of the species of reptiles sharing these habitats, were either directly dependent for a considerable portion of their food upon some of the seven primary amphibian species, or were partly or indirectly

## Table 2.

### Stream Series of Habitats.

| | Shaded Bank | Swampy Bank | Oxbow Swamp | Waterlily Association |
|---|---|---|---|---|
| Diemictylus viridescens—adult .... | R | F | C | C |
| Diemictylus viridescens—larvae ... | | | F | C |
| Bufo americanus—adult .......... | C | F | F | R |
| Bufo americanus—young* ........ | F | C | C | F |
| Hyla versicolor—adult ........... | R | | | |
| Rana pipiens—adult ............. | C | A | A | C |
| Rana pipiens—young* ........... | C | A | A | C |
| Rana clamitans—adult ........... | C | C | C | F |
| Rana clamitans—young* ......... | | C | C | F |
| Rana cantabrigensis—adult ....... | C | F | R | R |
| Rana cantabrigensis—young* ..... | C | C | C | F |
| Rana catesbeana—adult .......... | C | F | F | F |
| Natrix sipedon .................. | F | C | C | C |
| Thamnophis sauritus ............. | R | F | C | R |
| Thamnophis sirtalis .............. | F | C | A | C |
| Chrysemys cinerea ............... | | | F | C |
| Chelydra serpentina ............. | R | | | |

A=abundant, i. e., always found in numbers.
C=common, generally found on the average collecting trip to habitat.
F=few, occasionally found in the habitat.
R=rare, only a few taken during the four summers.
* =adult form, not tadpoles.

## Table 3.

### Lake Series of Habitats.

| | Open Water | Scirpus Assoc. | Water-lily Assoc. | Sand Beach | Beach Pool |
|---|---|---|---|---|---|
| Necturus maculosus .......... | R | | | | |
| Diemictylus viridescens—adult | | | C | | C |
| Diemictylus viridescens—larvae | | | C | | C |
| Bufo americanus—adult ...... | | | R | F | F |
| Bufo americanus—young* ..... | | | F | C | C |
| Rana pipiens—adult .......... | | F | C | F | A |
| Rana pipiens—young* ........ | | C | C | C | A |
| Rana clamitans—adult ........ | | F | C | R | C |
| Rana clamitans—young* ...... | | | C | | C |
| Rana cantabrigensis—adult .... | | | R | R | R |
| Rana cantabrigensis—young* .. | | F | F | F | C |
| Rana catesbeana—adult ....... | | | C | | C |
| Natrix sipedon ............... | | C | C | F | C |
| Thamnophis sauritus ......... | | F | | F | C |
| Thamnophis sirtalis ........... | | C | C | C | A |
| Chrysemys cinerea ............ | | | C | | F |
| Chelydra serpentina ........... | | R | | | |

## Table 4.

### Bog and Woodland Series of Habitats.

| | Chamaedaphne Bog | Thuja Bog | Upper Beach | Aspen Assoc. | Virgin Hardwoods | Disturbed Hardwoods |
|---|---|---|---|---|---|---|
| Ambystoma jeffersonianum | | | | | | R |
| Plethodon erythronotus | | | | F | A | A |
| Bufo americanus—adult | F | C | F | F | F | C |
| Bufo americanus—young* | | | C | F | | |
| Hyla versicolor | | F | | F | F | F |
| Hyla pickeringii | | R | | | | R |
| Acris gryllus | | | | | | F′ |
| Rana pipiens—adult | C | C | F | F | F | F |
| Rana pipiens—young* | F | F | C | F | F | F |
| Rana clamitans—adult | C | F | R | R | | F |
| Rana clamitans—young* | | | F | F | | |
| Rana cantabrigensis—adult | F | F | | | | F |
| Rana cantabrigensis—young* | F | F | C | F | | C |
| Rana catesbeana—adult | F | F | | | | R |
| Eumeces quinquilineatus | | | | | | R′ |
| Storeria occipitomaculata | | | R | F | | F |
| Heterodon platyrhinos | | | F | F | | F |
| Natrix sipedon | F | F | F | R | | |
| Thamnophis sauritus | C | R | R | | | |
| Thamnophis sirtalis | C | C | C | F | F | F |
| Liopeltis vernalis | | | R | F | F | F |
| Diadophis regalis | | | | R | | R |
| Terrapene carolina | | | | | | R′ |
| Lampropeltis doliatus triangulus | | | | F | R | R |

′=see annotated list.

dependent upon these amphibians, feeding upon them occasionally or upon other reptiles which in turn feed upon these amphibians. None of the primary amphibian species depend upon reptiles for food to any large extent, although some species as the bullfrog and greenfrog occasionally eat snakes. The primary amphibians however contribute to the food of each other in a measure as tadpoles and small frogs are eaten by large frogs as opportunity offers.

As the primary amphibian species are egg-laying forms, three types of habitats were considered in determining the habitat preferences of these species, (1) habitats of adults, those in which the adult animals were found, (2) transitional habitats, those in which the juvenile individuals were found, and (3) habitats of larvae, those in which the eggs were laid and the larvae developed. On the basis of habitat preferences the seven primary amphibian species were divided into three series, (1) those species which lay their eggs in the water and pass their larval life there, but as adults live either in or near the water, (2) those species

which lay their eggs in the water and pass their larval life there, but as adults live some distance from the water, and (3) the species (this series includes but a single species, *Plethodon erythronotus*) which lays its eggs and passes both larval and adult life in damp woods, away from water but in a moist habitat. These three series with their associated species include all of the amphibians and reptiles of the Douglas Lake region except one, *Necturus maculosus*, the only member of the fauna considered, which passes its entire life in the water. In the following paragraphs the interrelations of the amphibian and reptilian species are considered with reference to the groups outlined.

*Series 1. Preferred habitat of adults, swamp; habitat of amphibian larvae, aquatic.*

AMPHIBIA.

| Primary species | Secondary species |
| --- | --- |
| Diemictylus viridescens | None |
| Rana pipiens | |
| Rana clamitans | |
| Rana catesbeana | |

ASSOCIATED REPTILIA.

| Primary species | Secondary species |
| --- | --- |
| Natrix sipedon | Chrysemys cinerea |
| Thamnophis sauritus | Chelydra serpentina |
| Thamnophis sirtalis | |

Series 1 includes those species which frequent the swampy lowland of the region, although some of them at least often stray into other associations. The primary amphibian species of this group require still water with more or less vegetation for spawning grounds and during their larval stages. The larvae of *Diemictylus viridescens* spend one summer in this habitat (Hay, 1892, p. 455), as do the tadpoles of *Rana pipens* (Ruthven, Thompson and Thompson, 1912, p. 51). The tadpoles of *Rana clamitans* and *Rana catesbeana* are dependent upon this habitat for a longer time, spending two or three years in the water before transforming (Dickerson, 1905, p. 204). The newt also returns to this habitat after the second or third year and remains there as an adult aquatic form. This quiet water habitat is required by these species not only because the decaying vegetable and animal matter which forms a considerable part of the food of their tadpoles and larvae is more frequently deposited in still water than in moving water, but also because

these tadpoles and newt larvae are not strong swimmers and would be swept away by swift water. Hence this quiet water or pond habitat is the breeding ground and home of the larvae of all four amphibians of this series, and the habitat of the mature newt as well.

The sandy soil of the Douglas Lake region is not favorable to the formation of ponds, as is a clay soil. As a result, ponds are not common. There are, however, many small, deep lakes and small rapidly moving streams. Both streams and lakes are unfavorable to the formation of the pond habitat; the streams because of their own movement, and the lakes because of the action of winds and waves during the summer, and of ice-jams which plough up the shore during the winter. Pond conditions in this region are restricted therefore, almost entirely to the water-lily associations, which are found in the lakes behind sheltered points, in the quieter portions of the small streams, and in the large beach pools which have been cut off from some of the larger lakes. Consequently the young of these four amphibian species of series 1 are concentrated in these favorable localities, and are there often very abundant.

The bogs of the region offer pond conditions to some extent and these primary amphibian species are usually well represented in the vicinity of a Clamaedaphne bog (see tables). The Thuja bog however, if containing open water, rarely supplies the proper transitional habitats. The transition zone in the vicinity of the Thuja bog is usually a narrow one, connecting the bog abruptly with dense forest, a condition more favorable to the primary amphibian species of series 2.

The optimum habitat for the species of series 1 in the Douglas Lake region, as shown by the collections and field data, was the beach pool. The grasses and sedges which come into such a pool around its margin form an excellent transitional habitat for the young frogs, and if there be a swampy area of any considerable size adjoining the beach pool proper these same grasses and sedges may form the habitat of the adult frogs as well. Beyond the swampy area the type of plant association is of little consequence as the tension zone between the swamp and almost any other plant association found in the region could be used as a habitat by the adults of these three species of frogs. The ratio of abundance of these three amphibians varied however with the type of plant association beyond the swampy area. It was noted that bullfrogs were more abundant in the vicinity of a beach pool if the vegetation beyond the swampy area were hardwood or thicket than if it were open field or sand beach. In this connection it should be pointed out that, although a given species be listed in the tables as abundant in a particular habitat, it frequently was not abundant in small or isolated units of that type of habitat, the sequence of the adjoining plant associations

being an important factor in determining the abundance of a species in a particular area, granting that local conditions were favorable to that species. It was noted repeatedly that large Scirpus associations in rather shallow water, if adjoining a shore near a lily association were favorite habitats for young frogs of series 1, but small, isolated Scirpus associations, even if in shallow water, contained few frogs.

The primary species of reptiles of series 1 are three semi-aquatic snakes—the watersnake, the ribbon snake and the common gartersnake. As these three species of snakes bear living young, the breeding habitat is not a limiting factor in their local distribution. In this respect they differ from the primary amphibian species. The food of the watersnake includes fishes, both living and dead, small frogs and tadpoles. Other animals are also taken, but those listed form the most important portion of its food in the Douglas Lake region. Many of the watersnakes examined contained fish in the alimentary canal. In captivity watersnakes fed upon young frogs. Twice in the field this species of snake was seen to capture small frogs and swallow them. The watersnake was not as dependent upon the primary amphibian species of series 1 as were the two species of Thamnophis. These snakes, *Thamnophis sauritus and Thamnophis sirtalis* were observed many times in the field feeding upon young frogs, and the stomachs of several specimens dissected at the Biological Station were found to contain young frogs. *Thamnophis sirtalis* at least was not entirely dependent upon the primary amphibian species of series 1 for food, for on three occasions small gartersnakes of this species, less than two feet in length, were found choked to death by small perch, *Perca flavescens,* which had been partly swallowed, suggesting that the common gartersnake makes some use of small beached fishes for food. From the tables it may be seen that the two species of Thamnophis in general frequented the same habitats, in which they were about equally abundant, although considering all habitats of the region, the common gartersnake was the more abundant of the two. Usually the two species were not as definite competitors of one another as their habitat distribution might imply. *Thamnophis sauritus,* the ribbon snake, frequented the grassy portions of the habitats in which it was found and *Thamnophis sirtalis,* the common gartersnake, the more open, moister parts. It was also found in the water more frequently than the ribbon snake. In the old, almost filled beach pools and in the more completely covered portions of the Chamaedaphne bogs *Thamnophis sauritus* was the more abundant species. This intra-associational distribution of these two snakes seemed definite, although detailed data are not at hand for a complete comparison.

The secondary reptilian species of this series are two turtles. One of these, *Chrysemys cinerea,* was rather abundant in the deep water of the waterlily associations and was occasionally found in the larger beach pools. The other, *Chelydra serpentina,* was too rare in the region (see annotated list) to have any large connection at present with the general ecology of the amphibians and other reptiles. Both species of turtles are omnivorous (see Ruthven, Thompson and Thompson, 1912, pp. 135, 141 and 142 for summaries of the food of these species), although they may be dependent upon the primary amphibians of series 1 as their food includes tadpoles and the bodies of vertebrates dying in the waterlily associations.

*Series 2. Habitat of adults, woodland; habitat of amphibian larvae, aquatic.*

AMPHIBIA.

| Primary species | Secondary species |
|---|---|
| Bufo americanus | Ambystoma jeffersonianum |
| Rana cantabrigensis | Hyla versicolor |
| | Hyla pickeringii |
| | Acris gryllus |

ASSOCIATED REPTILIA.

| Primary species | Secondary species |
|---|---|
| Thamnophis sauritus | None |
| Thamnophis sirtalis | |
| Heterodon platyrhinos | |
| Natrix sipedon | |

The amphibian species of series 2 like those of series 1 require a pond habitat for the eggs and larvae. The tadpoles or larvae of all of the amphibians of series 2 however, transform during the first summer, and with the exception of *Acris gryllus,* before the first of September (Ruthven, Thompson and Thompson, 1912, pp. 31, 41, 43, 45, and 57; Dickerson, 1905, p 156). The more rapid metamorphoses of these species enables them to take advantage of less permanent breeding places than those required by the amphibians of series 1. The transitional habitats seemed the important ones in determining the local distribution of the amphibians of series 2. These species were not as abundant in and about lily ponds and beach pools which adjoined swampy habitats, as near lily ponds and bog pools which adjoined forest and woodland habitats. The upper beach connecting a woodland habitat with a lily

pond was the favorite habitat of young woodfrogs and toads during the last of July and the first of August. On Lancaster Lake in certain places the woods came almost to the water's edge and the upper beach zone was wanting. In the vicinity of waterlily associations on this lake the beach margin of the forest served as a transitional habitat for numerous young woodfrogs and toads.

The secondary amphibians of series 2 include those species which were not taken in large numbers, the rare or scarce species of amphibians of the Douglas Lake region.

The reptilian species of series 2 are three snakes, to which the watersnake, possibly should be added. The two species of Thamnophis fed upon young toads and woodfrogs in the transitional habitats, especially in the upper beach zone, *Thamnophis sirtalis* being the more important enemy of these amphibians because of its abundance and wide distribution throughout the Douglas Lake region. The hognosed snake, *Heterodon platyrhinos,* was found more frequently in the aspen association than in the upper beach zone, the only habitat of the three habitats frequented by this snake in the Douglas Lake region (see tables) in which large numbers of woodfrogs and toads were seen. The food of the hognosed snake seems limited to toads and frogs, the snake having a preference for toads (Ditmars, 1908, p. 382). Because of this choice of food the hognosed snake is very definitely dependent upon two of the amphibians of series 2. It is possible that the watersnake fed upon young toads and woodfrogs in the upper beach zone occasionally as it was seen in that habitat several times.

*Series 3. Habitat of adults, damp woodland, second growth forest or aspen; habitat of amphibian larvae, damp, rotten wood.*

AMPHIBIA.

Primary species
    Plethodon erythronotus

ASSOCIATED REPTILIA.

Primary species
    Lampropeltis doliatus triangulus

Secondary species
    Storeria occipitomaculata
    Diadophis punctata
    Liopeltis vernalis
    Eumeces quinquilineatus
    Terrapene carolina

With the exception of *Liopeltis vernalis,* all of the species of series 3 are forms which are found under or near fallen timber in areas more or less covered with a growth of trees. The grass snake is an insectivorous species and was seen most frequently in the low vegetation and underbrush in the disturbed hardwoods and second growth timber. This snake may be a part of the food chain of series 3 however, as Ditmars (1908, p. 386) states that the grass snake is eaten by *Storeria occipitomaculata.*

The red-backed salamander is the only species of series 3 which is abundant in the region, although it was not a conspicuous form in the woodland which it frequented. Restricted as this salamander is to damp, rotten wood during both larval and adult life, its local distribution was changed wherever the woodland had been cleared or cleaned of fallen timber.

The king snake, *Lampropeltis doliatus triangulus* is the only reptile of series 3 which was even fairly common in the region. This snake showed a decided preference for the drier parts of the aspen associations, although it was found in the damp woodland under fallen timber. The four snakes of this series may be arranged in a single food chain dependent upon the primary amphibian species of this series, *Plethodon erythronotus.* How important this chain is in the ecology of these species was not determined as too few individuals were collected (see annotated list). The food of *Diadophis punctata* includes *Storeria occipitomaculata* (Ditmars, 1908, p. 386) and the salamander, *Plethodon cinereus (= P. erythronotus)* (Surface, 1906, p. 173). *Lampropeltis doliatus triangulus* is reported (Surface, 1906, p. 179) as feeding upon *Storeria occipitomaculata,* although mammals seem to comprise a large portion of the food of the king snake (Surface, l. c.). A specimen of *Storeria occipitomaculata* taken in the hardwoods near North Fishtail Bay on Douglas Lake contained three red-backed salamanders, and the fact that the food of the red-bellied snake may include the grass snake has been mentioned previously.

The box turtle and the skink represented as they were by but a single specimen each in the collections of four summers are too rare to be considered in this connection.

*Series 4. Habitat of both larvae and adult strictly aquatic.* The mud puppy, *Necturus maculosus* is the only species in the fauna considered which comes under this head. This species is not common in the Douglas Lake region at present.

## SOME CHANGES IN THE LOCAL DISTRIBUTION OF THE HERPETOLOGICAL FAUNA.

The most obvious changes in the habitats of the Douglas Lake region have been those attending the removal of large areas of virgin timber by cutting, fire, or both. These changes in the vegetation of the woodland habitats have had a direct effect upon the fauna of the areas so altered. Where the land has been completely cleared a new forest of aspens has appeared and in the partly cut-over forest areas, the disturbed hardwoods, underbrush which is so conspicuously absent in the virgin timber, berry vines and second growth timber, have come up. These changes affect the upland and forest forms more than the semi-aquatic types of amphibians and reptiles. The fauna from the surrounding habitats overflows to some extent into the recently burned-over areas and in the growths of fireweed, *Epilobium angustifolium,* which are common in burned-over areas during the first two or three years after the fire. Woodland species, *Bufo americanus* and *Rana cantabrigensis* were frequently found near the undisturbed timber. In the underbrush and second growth timber which follow the fireweed, the grass snake, *Liopeltis vernalis* seemed to be increasing in abundance. After the burned over timber had fallen and begun to rot *Plethodon erythronotus* again appeared in the burned-over areas if there were sufficient vegetation to insure a moist habitat. *Rana pipiens* and *Thamnophis sirtalis* were often seen in rather open burned-over country, but always near some other more favorable habitat, and as has been noted in another section, these two species were more widely distributed than any other species of this fauna.

The semi-aquatic species seem to have suffered little in the region. Forest fires and the clearing of timber have disturbed the lakes, streams and especially the waterlily associations which are so vital to the success of the primary amphibian species, little if at all. Bogs have been burned over frequently, although the central body of open water usually remains after the bog timber has been destroyed.

A noticeable exception to the undisturbed condition of the aquatic habitats of the region may be cited as showing how important slight changes may be in determining the local distribution of species. A large number of gartersnakes were collected near a certain beach pool on Sedge Point, Douglas Lake, during the summer of 1915 for use at the Biological Station. Apparently correlated with this destruction of a dependent species of snake during the previous year, was a noticeable increase in the number of young frogs in the same habitat during the summer of 1916. Although young frogs, one of the regular items in the food of these gartersnakes in the Douglas Lake region were abundant, few gartersnakes were taken in this habitat in 1916.

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# DISTRIBUTION AND STRUCTURE OF THE EPIDERMAL SENSE ORGANS IN THE TADPOLES OF RANA CLAMITANS.

BY WM. KORDES BOWEN.

The larvae of many amphibia possess epidermal sense organs similar to the lateral line organs of fishes. This report deals briefly with the structure and distribution of the lateral line organs of the tadpoles of *Rana clamitans,* from which species they have not heretofore been reported. The species was determined by illustrations and descriptions in Wright's "North American Anura."

The tadpole possesses several rows of lateral line organs, which are located chiefly on the dorsal and lateral surfaces, although a few extend onto the anterior ventral surface. The distribution conforms to a definite system, with minor individual variations. These rows are made up of a series of light colored dots, each dot representing one or more of the sense organs. While the sense organs usually occur singly or in pairs, six or eight are sometimes found side by side. Kingsbury believes that such groups of sense organs are produced by fission from a single original sensory structure.

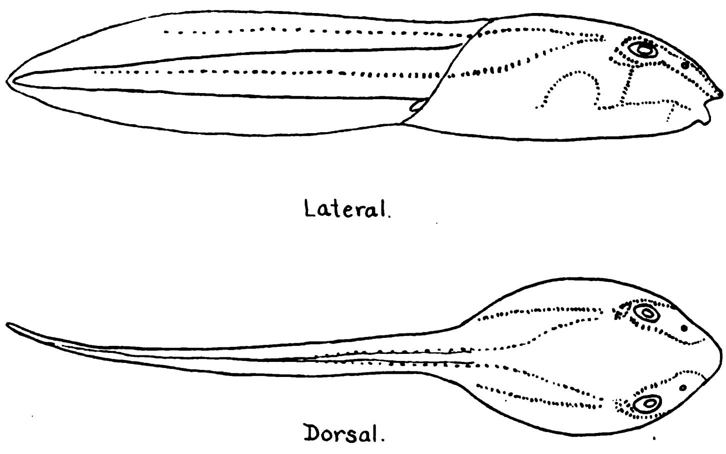


Figure 1. Tadpoles of *Rana clamitans,* showing distribution of sense organs. Length, 4 cm.

*Distribution.* Beginning from a point slightly behind the eye, two diverging rows extend backwards along the body and the tail. The inner

one runs along the upper half of the fin for about two-thirds of its length, nearly midway between the border of the fin and the myotomes. The second extends back, following the centre of the myotome region, nearly to the tip of the tail. A pair of short rows are located dorsolaterally on either side of the head. They run backward, one row of each pair passing on either side of the nares and the eye. Behind the eye, the organs are rather irregularly arranged, although one or more short definite rows may occur. The anterior lateral surface bears other rows of sense organs, as shown in the diagram, (Fig. 1.). The distribution of the lateral lines is practically identical with that in Rana catesbeana, as described by Kingsbury.

*Structure.* As regards structure, these sense organs, when seen in vertical section under the microscope, closely resemble taste buds. They are composed of a cluster of somewhat conical cells radiating from a more or less pronounced pit or crater in the outer surface of the skin. The cluster usually extends the full depth of the epidermis. Kingsbury recognizes two kinds of cells, a few shorter inner cells, surrounded

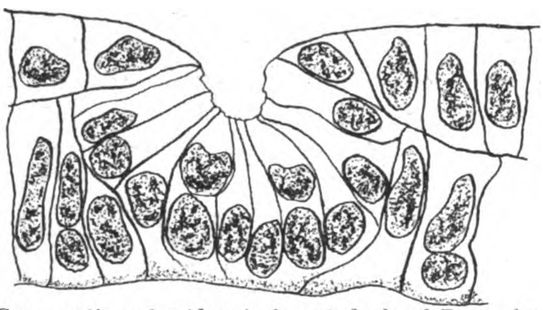

Figure 2. Cross-section of epidermis from tadpole of *Rana clamitans*, showing structure of a lateral line organ.

by several longer, slenderer ones. Fig. 2 shows two nuclei separated from the others, and lying nearer the surface, which probably represent the nuclei of the inner and shorter cells. The nuclei of the cells composing the sense organs are situated at the inner end of the cells, and the cytoplasm is relatively clear. The structures are, in general, similar to those figured by Kingsbury for the larvae of Amblystoma, and several other Urodeles, except that in the case of *Rana clamitans*, the cells comprising the sense organ are shorter and less numerous.

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# THE BIOLOGY OF ARCELLA.

BY A. G. PAPWORTH.

Since the discovery and description of the genus by Ehrenberg in 1830, *Arcella* has been a favorite subject for microscopic investigations. It is, without a doubt, our most common fresh water shell-bearing rhizopod, and may be found in a large proportion of cultures taken from ponds and streams. Combining amœboid simplicity of organization with a complicated system of reproduction, and added to this a shell rivalling those of the Foraminifera, it is scant wonder that for the past half century the literature on the subject has continued to accumulate. Many and diverse conclusions have been reached by separate workers. It is in an attempt to embody the most conservative of these in a connected account, together with personal observations, that this article is written.

## GENERAL DESCRIPTION.

In appearance, *Arcella* is distinctive. In spite of marked variations in form within the genus, it is not liable to confusion with any other common Protozöon. The comparison that inevitably presents itself on seeing the organism for the first time, is that it looks like a little doughnut. The yellow or brown color, circular shape, and small central opening, favor the simile.

From the side, however, the shell is seen to be campanulate in shape, broadest at the bottom, and wider than high. Across the bottom of the inverted bowl extends a continuation of the shell, covering the base except for a round central opening, one-fourth to one-third the diameter of the shell. The surface of the dome is generally smoothly convex, but may be pitted or faceted. The color varies from faintest yellow through brown, almost to black. Average dimensions are .1mm wide, .05mm high, with a mouth opening of .03mm. In all cases except very young individuals, a minute configuration or cancellation of the shell is visible. Unlike the related *Difflugias*, *Arcella* never has sand or other foreign particles incorporated in the shell.

Within the shell can be seen a mass of clear protoplasm of irregular outline, usually filling most of the shell cavity. Two nuclei are commonly visible, but there may be only one or many. Contractile vacuoles, gas vacuoles and food balls are features usually distinguishable without

special preparation. From the opening of the shell extend long, slender pseudopodia. The protoplasm is attached at base and dome in a wavy line.

### NORMAL BEHAVIOR.

Physiologically, *Arcella* is quite amoeboid, within the restrictions imposed by the shell and other factors. It progresses by the same pseudopodial action, and is similar in food relations. Due to the mechanical impediment of the shell, it cannot advance with the effective rolling motion of the larger amoebas, but must laboriously extend its pseudopodia, contract its protoplasm, and drag its shell forward. It creeps about the leaves of water plants and on the bottom debris of shallow, sheltered water. In a culture jar, its method of locomotion is evident, but progress is exceedingly slow.

Generally several long, clear pseudopodia are extended to one side. They are clear and transparent except for ingested food particles, and are normally simple, but may be branched. Now and then an individual is seen to extend a long slender pseudopod and wave it slowly back and forth. Some authors have interpreted this as "feeling for food," but to Calkins ('10), it suggests the origin of flagellar structures.

In its food and feeding habits, the present genus is not markedly different from the better described *Amoeba*. The pseudopodia are so long and slender that it is confined for food to the ooze of decaying vegetation, and to certain algae. Although a considerable part of the body protoplasm may be extruded from the shell, the latter is an effective hindrance to engulfing large and vigorous Infusorians.

If a food particle is encountered small enough to be manipulated by the thread-like pseudopodia, it is ingested and passes slowly to the body mass, where digestion is completed. If it is too large to be disposed of in this way, other pseudopodia may be projected and the whole body drawn up to a point over the particle. Within the body the nutriment is absorbed and the indigestible particles egested. This naturally occurs at the mouth of the shell, so that there is a localization of egestion slightly in advance of the amœba. Contractile vacuoles are numerous and active. There is no evidence that any particular selection of food occurs. There is, however, a degree of discrimination indicated by the fact that sand particles and other indigestible materials are not ingested to any great extent.

In cultures rich with algae, the Arcellas creep about and become filled with the smaller organisms in normal fashion. An astonishing phenomenon, however, is the ingestion of a filamentous alga twenty or thirty times as long as the diameter of the shell. How it is possible for the animal to coil the long strand within its shell is a problem, but the fact

remains that it is often so found. After watching the operation a number of times, it is my conclusion that the phenomenon is due merely to the shape of the shell and filament and the nature of the engulfing force. An end of the strand is encountered and ingested. As it strikes the dome of the shell, it bends to one side or the other, and continued exertion results in the coiling of the filament as the most conservative mechanical mode of disposition.

As a matter of fact, similar cases are observed in the inorganic world. Calkins ('10) states that a drop of chloroform will draw in a thread of shellac in the same way, as will also egg albumen with gum arabic. The implication is that many of the vital processes of lower forms, like ingestion and excretion, are not different in kind from physical processes occurring quite outside the organic realm.

### GAS VACUOLES.

The possibility of another mode of locomotion than that of pseudopodial progression has received considerable attention. Long since, at least by the time of Engelman ('69), gas bubbles were observed in Arcella, which grew in size and then subsided, apparently without reference to external conditions. Since that time these have been considered as hydrostatic organs, capable of raising or lowering the body in the water. Whether or not this function is purely a myth is not yet clear.

The gas bubbles appear in all places in the body, are irregular in shape, and have no constant relation to the nucleus and contractile vacuoles. Khainsky ('10) remarks that the change in volume usually occurs in all the bubbles of one individual at the same time. This has its exceptions, as not all the bubbles change size at the same rate.

The nature of the gas contained has been variously regarded as oxygen, carbon dioxide, and atmospheric air. Dr. Khainsky (op. cit.), who seems to be the only recent worker on the subject, declares the gas to be neither oxygen, carbon dioxide nor sulphur dioxide, as indicated by appropriate tests. Furthermore he states that they do not appear in cultures where there are no algae, that they grow at night and diminish by day, and are never present in young individuals. Finally he surmises that the bubbles gain access to the shell by the animal climbing to the surface film and elevating the shell into the atmosphere by pseudopodial action. His conclusion is equally remarkable: "The gas bubbles play no physiological role with Arcella, and for the organism itself are only harmful. The Arcellas which contain gas vacuoles ——— always die." "In den Fällen wo die Arcellen mit Blasen an irgendeinem Gegenstand anhaften, pressen sie die Gasblasen durch die Schale heraus," assuming the shell to be porous.

My own incomplete observations, covering some months with many thriving cultures, give no direct evidence of hydrostatic activities, although the bubbles themselves have been numerous. I have never found Arcellas in a location where they might not normally have arrived by other means.

My theory of the origin of the gas vacuoles is in line with Khainsky elsewhere. The newly formed Arcella has a shell very soft and flexible so that it yields to the contractions of the protoplasm. As it becomes hardened, it no longer gives with the same ease. The contracting protoplasm pulls away from it, forming a slight vacuum, into which the dissolved gas of the culture evolves. Under pressure again, this redissolves, thus accounting by a simple physical law for the irregularity of the appearance and disappearance of the vacuoles. Such a process would alter the specific gravity of the organism, but whether it would be sufficient to accomplish flotation is not certain.

## THE SHELL.

General Features. On the basis of shell morphology, the genus Arcella is customarily divided into half a dozen species. The type species, *A. vulgaris* Ehgb. has been mentioned. *A discoides* Ehgb. is lower and broader, generally shield-shape. In *A. mitrata* Leidy the shell is mitriform, higher than wide, and widest at or near the middle, generally with the sides of the dome divided into regular facets. *A. dentata* Ehgb. is characterized by pronounced dentate processes around the base.

In spite of these rather conspicuous differences, the forms intergrade completely, so that it is impossible to be certain of the specific rating of many individuals. The statement is made (Claparede and Lachmann and others) that individuals of one form may produce others totally dissimilar, so that the specific nomenclature is valid for convenience of description only. Occasionally I have found an abnormal shell, but such are quite exceptional. A noteworthy case was one with a double mouth opening. Pseudopodia proceeded from one or the other without discrimination. Other abnormalities apparently have resulted from injury, with incomplete regeneration of the part lost.

*Minute Anatomy.* The details of the finer structure of the shell have been the subject of much discussion. A regular cancellation of the surface is apparent, even with moderate magnification, but the nature of the construction is not so clear. The stock description has been that of Leidy ('79), who states that the test "is composed of a more or less translucent or transparent chitinoid membrane, with a minutely cancellated hexagonal structure." From the text and figures, it is plain that he considers the shell to be composed of closed hexagonal chambers like

those in a honeycomb. This idea may be traced to Hertwig and Lesser ('74), who, after considering and rejecting former views, declare positively: "Ihrer feineren Struktur nach besteht die Schale aus zwei Platten, einer äusseren und einer inneren, welche einander parallel gelagert sind, und durch ein bienenwabenartiges hexagonale Figuren bildendes Fachwerk vereint werden."

The same authors treated the shell with sodium carbonate and acetic acid, whereby bubbles were formed in the cancelli, showing them to be hollow. The fact that the chambers were closed above and below has never been questioned until recently. Cushman and Benedict ('06) are of the opinion that there is only one membrane, the inferior one, so that the cancelli are open above. They say that by exposing the shell to the air, bubbles collect in the chambers without further treatment. Excellent photomicrographs showing this result are included in the work, and they state that in cross sections no superior membrane appears. On the contrary, however, the later careful work of Khainsky ('10) indicates both membranes in sectioned preparations. It is barely possible that both are right. If the original cancelli were constructed with delicate end plates, it is conceivable that these might later be ruptured or dissolved.

Aside from this point, the fine anatomy of the shell seems to be complicated beyond the conception of the earlier writers. Cushmann and Benedict ('06) give photomicrographs which show clearly that the structure is not the simple hexagonal one usually figured. In the typical hexagonal structure, all six sides are in contact with similar sides of other hexagons, while in the shell pattern of Arcella, the sides of the hexagons are never in contact with each other, but with smaller triangular figures. The scheme may be reproduced by drawing three sets of parallel lines at an angle of sixty degrees with each other.

*Origin and Formation.* The manner of construction of this complicated shell is worthy of note. For a long time, it has been a common observation that new Arcellas were formed by fission and constructed a new shell from intrinsic material. This rudiment of the shell is so flexible and transparent that it has generally been held to be structureless. Khainsky, however, discusses certain *intra vitam* stains which render the structure visible during formation. He states that after the emergence of the protoplasm from the cavity of the maternal shell, a clear delicate membrane is secreted around the projecting plasma. This under sufficient magnification exhibits an irregular foam structure, with larger and smaller alveoli promiscuously intermingled. At this time, these are plastic and flexible. As growth proceeds, due to side pressure they become higher and assume the typical hexagonal shape, with the smaller alveoli filling the interstices between the larger. At this time the shell of the

new Arcella is closely united to the ectoplasm of the maternal sarcode. Soon the shell begins to take on its characteristic shape, and fission of the protoplasm results in two daughter cells, each with typical amoeboid activities. The young cell is distinguished by a lighter color, which gradually deepens with age.

Chemical and Physical Characteristics. As has been anticipated, the shell of Arcella is chitinoid in composition, resembling the protective exoskeleton of the Arthropods. It is insoluble in all ordinary acids and alkalies, a feature of immense significance to the organism. In some experiments of my own, digestion in water at room temperature for half a year failed to produce any appreciable effect, while it reduced insect structures entirely, with the exception of the elytra and mandibles.

The brownish color is evidently due to iron salts deposited in the shell substance. Awerinzew's "Arbeit nach enthalten die Arcellashälen Eisen," as well as Khainsky's statements, support this view. Further support is derived from the fact that the animals thrive best in water rich in minerals, and do not propagate in the acid water of bogs where Actinophrys is found. As to the general chemistry of the shell, Khainsky suggests that in the young shell an oxyaminoacid is present, which is altered with age by the substitution of iron.

## REPRODUCTION.

The reproductive processes in Arcella are remarkably varied and complex for an animal of so simple organization and especially one of free-living habit. All the elementary types of reproduction known in the Protozoa have been described for this single genus.

*Fission.* The simplest manner of reproduction is that in which a mature animal divides into two daughter cells, and it is this type of propagation that was first described in the genus. As physiological maturity is reached, the protoplasm of the maternal cell proceeds to the mouth of the shell, where, by the absorption of water, it swells to a size equal to or greater than the shell. A new shell membrane is formed which takes the characteristic shape immediately. This gives the phenomenon of two shells applied face to face, with the sarcode mass within. While further development of the shell proceeds, there occurs a thorough manipulation and reorganization of the nuclear material. The two nuclei finally divide simultaneously, and at the end of two to four hours from the start of the process, equal fission occurs, resulting in two individuals, which after a period of inactivity, resume the ordinary life activities. This is one of the more common reproductive processes, and occurs with some frequence under all living conditions, but, as with other types, is subject to epidemics under suitable environmental states.

*Budding.* A form of unequal fission known as "Knospenbildung" has been observed by Swarczewsky ('08) and others. The first indication of this process is the disintegration of the nuclei into fragments which are distributed throughout the body plasm toward the periphery of the animal. These particles are recognized as "bud-nuclei" of characteristic appearance. Now a portion of the protoplasm differentiates itself by becoming denser and more refractive. This portion, containing a bud-nucleus, separates from the parent and passes out of the shell in amœboid form. After sinking to the substratum, it develops an investing membrane, undergoes a resting period, and finally develops directly into a normal individual.

*"Agamoganie."* A related phenomenon is that referred to by Elpatiewsky ('07) under the name Pseudopodiosporenbildung. The amœboid spores arise in the same manner practically, and emerge from the shell one after another. After creeping about the opening of the shell for a considerable period, they assume a heliozöoid form with radiate pseudopodia and vacuolated structure. Such forms have often been observed in cultures, and have been assigned to various places in the order.

Swarczewsky's observations ('08) have not been in entire accord with these. He declares that the "agametes" leave the shell immediately. Five were described as leaving at one time, followed in five minutes by two more. I have never seen more than one or two such structures at a time, and only seldom. The phenomenon is said under certain conditions to be found in all the individuals of a culture. Occasionally the whole mass of protoplasm may desert the shell and wander almost in irregular amœboid shape, giving off numbers of these smaller forms.

*Sporulation.* The formation of two kinds of gametes, which conjugate and later form a resting stage which subsequently develop into adult forms, has been described by many authors. Ill understood as this phenomenon is, it seems to be one of the customary methods of reproduction in many of the Protozoa. The adult body breaks up into nucleated fragments of one of two kinds. These "micro" and "macro-amœben" emerge from the shell and progress by means of short, broad pseudopodia. Finally they become symmetrically radiate, and copulation occurs between the two forms. The subsequent history is probably the development of a cyst, and final production of a shelled form.

*Plasmogamie and Conjugation.* Often normal fission is interrupted by what generally passes for conjugation. Two individuals of the same appearance are applied face to face, with the body protoplasm united, while a slow mingling of materials occurs. I have endeavored to follow this process through in many cases which I have observed but have never been able to find any definite results. After long union the individuals

separated and went on as before. It is Elpatiewsky's opinion that the ultimate result of the operation is sporulation of a special type, but the proof is not conclusive.

One of the common figures of Arcella in texts shows three individuals with the body protoplasm united. This may have some bearing on reproduction, but in many cases at least, no nuclear changes are observed, and it is possibly only plasmogamie. The naked protoplasm of the animals is naturally viscous, and when two or more come together they adhere mechanically, without any especial physiological implication. This is very commonly the case with the Heliozoa, in which groups of individuals are often united by a protoplasmic isthmus. It is nevertheless possible that some benefit in the form of rejuvenation follows such protoplasmic contact. Swarczewsky makes the distinction that conjugation (Chromidiogamie) is a process sugeneris, and can be brought into no necessary relation to plasmogamie. Further observation on the phenomenon of plasmogamie in this and other forms is needed before positive conclusions can be drawn.

*Encystment.* The occurrence of encystment is common throughout the Rhizopods, as well as the other Protozoa, and in time will probably come to be recognized as an almost universal method of tiding the organism over a period of drought, cold, lack of food, or other unfavorable circumstances. Other closely related Rhizopods whose cysts have been recorded are Nebela and Euglypha (Prowazec '00), Difflugia (Rhumbler '96) Centropyxis (Schaudinn '03), Chlamydophrys, Amœba, etc.

With respect to Arcella, cysts of various kinds have repeatedly been described. Most of this literature is fragmentary and not easily available. The thesis of Dr. Martini, ('05) prepared under Hertwig, seems to be the most extensive work on the subject. Fifty pages of text with sixty-nine figures deal with the formation, description, and development of the cysts. Many individuals with six nuclei had been observed, and the next examination revealed numbers of cysts, as well as many abnormal individuals in the process of encysting. An epidemic of cyst-formation resulted in most of the Arcellas in all the cultures passing into this dormant condition. Those that were left multiplied rapidly, and about a month later began a second period of encysting. This agrees with the observations of Hertwig and Lesser ('74 and later), who describe many spherical cysts within the shells, close to the mouth. The first indication of encysting in the 6-nucleate forms was a reorganization of nuclear material, accompanied by an increase in the number and size of the vacuoles. At the same time with the protoplasmic streaming certain characteristic "soft-bodies" could be discerned. After the disappearance of the vacuoles and extrusion of part of the chromatin, the proto-

plasm invested itself with a resistent shell, structureless, but similar in composition to the normal shell. With this preparation, the organism is apparently in a condition to withstand desiccation, freezing, etc., for long continued periods. After the expiration of minimal length of time, determined by internal factors, upon finding a suitable environment, the shell is resorbed, and the animal resumes sexual activity.

In my cultures I have at present (Feb. '17) many cysts, some like those described, but more in which the animal goes into dormant condition without marked bodily changes. The protoplasm is withdrawn into a ring in the dome of the shell, with the two nuclei plainly visible, but somewhat modified. There is no pseudopodial action evident, nor are the contractile vacuoles visible. A membrane across the mouth has often been mentioned under similar circumstances, but I have been unable to find any. Occasionally some of the encysted animals become active, but I have been unable to initiate a renewal of activity by changes in the culture medium, temperature, light and other factors.

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# GEOLOGY AND GEOGRAPHY.

# PROPOSAL OF AN AGRICULTURAL SURVEY ON A GEOGRAPHIC BASIS.

BY C. O. SAUER.

The immediate occasion for this paper is the proposed establishment of a soil survey by the State of Michigan. The creation of such a survey marks an important step in government aid to the development of the resources of the state. The manner in which it is organized at the outset will virtually determine the effectiveness of the entire project. A county is surveyed but once, and afterthoughts are of no avail. A full expression and exchange of opinion by the interested parties is desirable therefore at this time. The geographer is one of these interested parties, not numerously represented to be sure, but as his interests correspond in the main to those of the farmer and business man, their definition may be of general value.

Geography is a young science, concerned with a vast field. It is necessary therefore to select the most urgent lines of study and to concentrate upon these. The most urgent demand of the science is along lines of regional studies, to supply a larger body of systematic observations than are now available. In the prosecution of such studies geography is handicapped by the lack of formal surveys such as have been developed in most of the other natural sciences. In the past there have been so-called geographic surveys. In the future, there may be provision for truly geographic surveys. But at present the geographer must rely in large part on the field work of other scientific organizations, as geologic, typographic, biologic, and soil surveys. The manner of their execution therefore is of great moment to the success of regional geography, on which in turn the development of the entire science of geography depends in considerable measure.

In the United States, the soil surveys are undoubtedly the greatest single aid to regional geography, partly because of the importance of rural interests in our country, but more particularly because of the specific form which the soil survey has taken. It has been conducted almost entirely by the Bureau of Soils of the Department of Agriculture, and as thus carried on has the primary purpose of suggesting improvements in agricultural practice and of guiding the prospective purchaser of land in his selection.* It is evident immediately that such a survey must concern itself with many more things than the classification of soil types and their mapping. The survey inevitably becomes an inquiry

19th Mich. Acad. Sci. Rept., 1917.

*See Whitney, Yearbook Dept. Agric., 1901, 117; Bonsteel, ibid. 1906, 181; Whitney, Bureau of Soils Circular 13.

into the agricultural conditions and possibilities of the region, or, in other words, tends to become a study in rural geography. Accordingly, it must take into account pretty well the entire rural environment, including not only soils, but surface, drainage, climate, markets, character of population, and stage of development. The Bureau of Soils in its county reports is taking cognizance of a number of factors other than soils. The following notes on their more recent field operations will serve to establish the present scope of these studies.

The usual unit of Bureau of Soils reports is the county, and the reports as a rule, are highly standardized. With minor variations, the plan of one county report holds for almost all others. The Soil Survey of Cape Girardeau County, Missouri, may serve as a type. It consists of 48 pages and a soil map on the standard scale of one mile to the inch. Almost exactly one-half of the text is devoted to the discussion of the properties and uses of soils. The report begins with a formal statement of the location of the county and of the character of the topography, including some indications of its physiographic origin. Perhaps a majority of the reports do not attempt any physiographic statement. Drainage conditions, history of settlement, population of the county, and a sketch of the nature of the original vegetation, comprise the other topics which are included under the somewhat ill-defined heading "description of the area." A section on climate, with the usual meteorologic tables, follows. The discussion of agricultural practices concludes that part of the report which is given over to topics other than soils. In this particular instance the ratio of the general description to the soils section is unusually high. Usually at least two-thirds and not uncommonly more than three-fourths of the total space is given over to soils. The usual order of effectiveness is, soils first, farm practices next, the other topics good to very indifferent. An occasional report is characterized by originality of plan and careful analysis of the economic problems of the district.* Whatever the effectiveness of treatment, an attempt is always made to introduce a statement regarding agricultural conditions and opportunities.

It is recognized therefore, in part at least, that the soil survey is not an end in itself, but a means to a better understanding of the agriculture of a given district. Any modifications of existing procedure which improve this understanding must be considered desirable, whether they are associated with soils or not. In other words, is not the soil survey a preliminary step to a more comprehensive study of farming districts, a study in which the problems of farm production are viewed from various angles? By expanding some of the lines of inquiry which to date have been of minor significance in soil surveys, restricting some of the technical phases of soil studies, and adding certain new features, the soil survey will readily evolve into an agricultural survey. A proposal for such a broadening of scope is embodied in the following sections, to be organized on a geographic basis. The program as outlined, in practice would be subject to many modifications. The peculiar

*Reports of this type in the 1913 Field Operations of the Bureau of Soils are those on South-Central Texas and on Stevens County, Washington.

needs of the individual area must dictate in each case the best manner of treatment. The purpose of a survey of this kind is to be of greatest use to those who are most interested, and is not the publication seriatim, by units, of a uniformly executed reference work on soils or even agriculture for a state or for the country at large.

1). The least significant thing about a location is to give its exact position. The most important thing in the location of a rural area is its distance to markets and their accessibility. A sketch map, accompanied by a few words of explanation can show readily the major markets to which the district ships, the transportation lines involved, and, in some cases, potential markets with which commercial relations may be established.

2). Topography and drainage should be described, usually as one topic, but the enumeration of topographic features and of streams is not worth while. The map supplies all this information better than the text possibly can do. Geographic place names, unrelated to other facts, are of no more value in soil reports, where they still persist, than they are in grade school geography, where they have been long since abandoned. It is pretty well demonstrated that for layman and scientist alike the best presentation of surface features is by means of casual description, that is, describing them in terms of their origin. A belt of low, short hills acquires a new significance when it is stated that it is a terminal moraine. This method not only gives a more accurate sketch than the purely descriptive method, but in the long run it is an economy of space as well. That topography and drainage may be portrayed simply in physiographic terms, has been demonstrated amply by the educational bulletins that have been published by several state geological surveys. That this may be done effectively is indicated by the large demand for these bulletins on the part of the residents of the areas concerned.

3). The classification of soil types has been a most fruitful source of dispute and cause of the division of soil students into opposing camps. No single basis of classification can in general be carried through consistently without defeating the practical purposes of a soil survey. In all soil studies Hilgard's principle is applicable: "The many different points of view from which the subject may be approached precludes the adoption of a strictly uniform plan. We may approach the matter from the geological, physical, chemical, or botanical standpoint, as well as from that of the practical agriculturist; but neither of these, alone, will be found satisfactory; for soil-classification must always depend more or less upon the numberless and infinitely varied local conditions that influence vegetation, and must be correlated with these."* Contrasts in kind and amount of growth must be the ultimate criteria by which soil types are differentiated. Hilgard had this in mind in classifying soil types by natural vegetation, wherever

*Overland Monthly, Dec., 1891, p. 3.

significant. His soil map of Mississippi still stands as one of the most useful and readily intelligible soil studies that have been made. In it the farmer's viewpoint dominates and no attempt is made to vindicate any particular scheme of subdivision. In the State of Michigan, with its surface materials determined largely by glaciation, Leverett** and Sherzer*** have demonstrated the general utility of origin as a guide to the classification of soils.

4). Local names of soils should be retained wherever possible. One of the most difficult things in the use of federal soil maps by the average person is the recognition of the familiar soils which are concealed by their standard system of nomenclature. The layman, for instance, is not helped by giving to the simple soil types of the glacial prairies of northern Illinois such imported names as Carrington, Miami, Fox or Waukesha, which cannot possibly come into general use. Different types of alluvial soils are designated as of the Huntington, Holly, Wabash, and other series, although the localities from which these names are derived may be hundreds of miles distant from places where they are applied. Evidently alluvial soils are not identical over such areas, but only similar. Loess is known as Knox silt loam. The attempt is made to proceed in classifying soils with stratigraphic precision where nature herself has drawn no hard and fast lines. The placing of every soil of the United States into its own particular pigeon-hole which is supposed to be in definite alignment with every other pigeon-hole undertakes an impossible, and what is more, an unprofitable task.

5). In many localities the value and utilization of land is far more dependent upon slope than upon kind of soil. In some places it is almost the only soil consideration of practical importance. The relation of soil to slope is a negligible local factor only in smooth plains. Present soil surveys neglect this important consideration almost entirely. In mountainous areas the federal survey uses the designation "rough, stony land" for non-agricultural slopes, partially soil-covered. A few soil maps are printed on topographic bases. No consistent attempt has been made, however, to show steep slopes on soil maps. It is manifestly impossible to hold up soil studies until toporgraphic maps are available. Excessive slopes may be represented, however, without a topographic base, by indicating through shading or similar means the slopes that exceed a certain angle. There is probably not even for a single soil type in an individual area a definite angle beyond which cultivation becomes inadvisable. The manner of cultivation and kind of crop produced make a sharp separation of agricultural from non-agricultural land impossible. It is easy, however, to indicate on soil maps slopes on which the use of the land becomes affected by their steepness, whether field cultivation is prohibited or not. By supplying this most needed information regarding slopes the value of many soil maps would be increased several fold.

The following illustrations of the importance of slope are taken from observations in the Ozark Highland: "In general the most desirable soil types are those which are associated as a rule with gentle slopes,

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**Map of Surface Formations, Mich. Geol. Surv., 1911.
***Geology of Wayne County, Mich. Geol. Surv.

the undesirable ones those found for the most part in regions of great relief. The physical and chemical characteristics of soils are much less significant than the attitude of the surface on which they lie. The dissected margins of areas of Springfield soils, in general the most desirable residual type of the region, are in many places as unproductive as is the poorest Clarksville land, the least used soil of the region. The two types in general are strongly contrasted because most of the Springfield soil is on level prairies, the rock-formation from which the Clarksville is derived, however, expressing itself principally in rough hillsides. Low-lying solution basins in tracts of Howell soil, generally second-class land, furnish farming areas as choice as can be found in the Ozarks. The most important thing about the residual soils, therefore, is their depth, which in turn is dependent on the topographic expression of the rock-formation from which they are derived and the position of the area with reference to drainage lines. In Osage County, excepting the loess lands, the type of soil is not so significant in determining the value of land, as is the slope of the surface. Parts of the Union soil are worth as much as 50 dollars an acre on the level uplands. Near the rivers, however, where dissection has been extensive, this soil forms some of the cheapest land in the county, worth five dollars an acre and less. In Pulaski County, situated in the interior of the Ozarks, land values have little relation to soil types, with the exception of the alluvial lands, which have satisfactory depth because of their position. Prices on the upland are determined almost entirely by the amount of dissection, and the distinction of soil types for practical purposes becomes almost a matter of indifference."*

6). An agricultural survey offers an unusual opportunity for the practical application of climatic studies. The usual meteorological tables mean very little to the average reader. They should be condensed to the minimum amount of statistical material and for the rest replaced by a brief interpretation of the climate. Average length of growing season, frequency of unseasonable frosts, depth of frost action, amount and duration of snow cover, distribution of rain during growing season, frequency of droughts and rainy "spells" at critical periods, intensity of precipitation, occurrence of hail and violent wind storms—these and other topics will readily suggest themselves as appropriate objects of inquiry. Official weather records may be amplified by the weather experiences of the farmer, who is a valuable observer if not a satisfactory theorist. Local data regarding the relation of topography to frosts are available in many places.

*Author's manuscript "The Ozark Highland of Missouri."

7). The addition of the following features will aid in the presentation of agricultural conditions:

a). In most regions there exists a distinct farm type. A description of general farm practices can indicate only imperfectly the nature of this type. Usually it is not difficult to select an individual farm which will approach very closely to the type condition. If for such a farm, the system of farm management be described briefly and a sketch made of the use, character, and location of fields and of improvements, a concrete example of an average farm is supplied that will be of great value in understanding the rural economy of the district. In many counties one or more farms are far in advance of average conditions. In some cases such a farm may be cited as representing in a sense an ideal type toward which the development of the region will tend.

b). One-fourth of the 1918 soil reports were illustrated with an average of four half-tones each. The other three-fourths are not illustrated. The contrast in the intelligibility of the reports of the two groups to one who is not familiar with the ground demonstrates that the photograph is quite as indispensable a vehicle of description in agricultural reports as it is in areal studies of other kinds. Topography, character of unimproved land, fields in crop, manner of tillage, nature of farm buildings are in some instances of such a nature as to require photographic illustration for effective presentation.

c). A large part of the information regarding agricultural conditions can be summarized in a map which shows the uses to which the land is put. This map, primarily economic in nature, is the natural complement of the soil map. Attempts of numerous kinds have been made to map the economy of the land, with varying degrees of success. One of the most notable of these is the map of the "Distribution of Cultures in the Austrian Alps" by Norbert Krebs. In this the following conditions are represented: barren ground predominant, grazing land predominant, forest predominant, meadows in excess of fields, fields in excess of meadows, fields in excess of 50% of the total area.* The grouping is by large headings as the scale of the map is small. A far more ambitious map of similar nature is published as the Botanical Survey of Scotland, which is not botanical in the ordinary sense, as it shows primarily the uses of the land. The map shows such areas as "Cultivation with Wheat," "Cultivation without Wheat, oats chief crop," and "Hill pasture with grasses predominant."** In the State of Michigan the classes of land to be differentiated would include the following: 1) Land appropriated to residential and industrial uses; 2) barrens, or

*First published in Festschrift dem deutschen Geographentag zu Innsbruck (1912); also in Landerkunde der Osterreichischen Alpen by the same author.
**Scottish Geog. Mag., XX, 617; XXI, 28, 57.

areas permanently unproductive because of scanty soil; 3) bogs and swamps, perennially wet; 4) marshes and meadows, less wet than the preceding type, and yielding hay or suitable to grazing; 5) forested areas; 6) permanent pasture lands; 7) cultivated lands. Land that is occupied by cities, factories, and transportation lines is unproductive, in the ordinary sense of the word, and should be distinguished from the producing areas. Barrens are in the main areas of bare rock and of unstable sand dunes. Land that is continuously wet may be classed according to its origin as river-swamp or glacial bog, and further by the dominant vegetation. Wet, grassy land that dries out sufficiently to make it of use for hay or grazing should be distinguished from the more swampy tracts. Forested areas may be subdivided according to their tree associations, and as well into tracts of standing and cut-over timber or slashings. Seriously burned tracts, in which the soil is partially destroyed, may be indicated in some places. The cultivated lands are to be classified by the dominant crop or the type of cultivation. There will thus be areas of field cultivation with corn, wheat, hay, beets, or some other crop dominant, and areas with garden, vine-yard and orchard cultivation. Many other uses can be represented, but enough has been outlined to show that such a map is the logical consequence of soil studies. As in the mapping of soils, the units represented should not be too small, probably 10 to 40 acres as a minimum. Otherwise the problem of mapping becomes excessively complicated and tedious and the map loses its value in a brief period.

A map of this type unfolds a complete panorama of the rural conditions in a county. It will enable comparative studies in rural economy that are now impossible. For the geographer especially, it will supply much material now unavailable. To the prospective purchaser it supplies a bird's-eye view of stage of development and character of farming conditions that can be equalled only by spending much time on the ground in making careful observations. It will prevent many of the regrets attendant upon purchase of land with a few bits of information regarding farm conditions. If properly executed such a map will not readily become antiquated. In Southern Michigan, as in large parts of the Middle West, farm practice is pretty well established. There are many areas in which such a map if it had been made 25 years ago would need few alterations. If, in an old farming district the character of farming changes, it is important to have it recorded. To a careful purchaser the past history of land may mean nearly as much as its present appearance. The drainage of swamp lands, abandonment of grain production, introduction or abandonment of orchards are instances in point which it may be desirable to know. If the region is beginning

its agricultural development, as northern Michigan, then, it is true, a few years will see striking changes. The map then does establish, however, the primitive character of development, and puts into their true light the conditions which the settler will need to face. A map of uses of the land at such a stage serves a much more important purpose as well. It will indicate primarily the distribution of forests and their dominant trees, of prairies, meadows, swamps and barrens. In short, it shows primarily the distribution of native types of vegetation. Hilgard, in fact, urged that this is the time to make a soil study, when man has not disturbed the order of nature. From this native vegetation can be deduced "the same results we now gather from long experience, or from culture tests with fertilizers.. It is, then .. important that the original state of things should be put on record as quickly as possible."* In such a new area the map would be an index not only of the agricultural fitness of the soil, but would give indications as well of the difficulty of clearing and otherwise reclaiming the land. Whether the area be young or well developed the execution of such a map will be helpful.

These proposals embody some ideals of the geographer, in the working out of which he believes that his science eventually will participate. Here it will find the opportunity for practical field work, which alike will benefit the progressive resident of the area, protect the home-seeker, and accumulate valuable information for the student of rural conditions.

University of Michigan, March 29, 1917.

*Cited above, p. 81.

# ON THE PROSPECT OF OIL BEING FOUND UNDER THE ONTARIO-OHIO-MICHIGAN SECTION OF LAKE ERIE.

BY THOMAS NATTRESS.

From Detroit City to the inter-state boundary of Michigan and Ohio on Maumee Bay there is a long line of deep wells that have developed pockets of gas and showings of oil. But not even in the Potter well in Erie Township, at the southeast corner of Monroe County in Michigan, and in close proximity of the Toledo field was there more than "some gas and some oil."

Mr. R. A. Smith[1] of the Michigan Survey, reporting upon Monroe County, has stated logically the conclusion for the entire distance traversed: "Monroe County is too far down the western slope of the Cincinnati anticline to contain oil and gas in any great quantity."

On the Ontario side of the northern reach of the Cincinnati uplift, in Essex County, there is little gas and less oil in the Malden and Colchester wells; little oil and much gas in the Kingsville-Leamington field; and on Pelee Island some gas and some oil. The Ontario-Ohio system of islands, shoals and points of land across Lake Erie from Pelee Island to Marble Head is also, from all the evidence to be adduced, lateral to a main supply and too far down the *eastern* slope of the Cincinnati uplift for quantity.

Eastward of this section there is no indication of any series of anticlinal folds that might hold a main supply. Westward there is the Cincinnati dome, with minor transverse folds, at least in the rocks of the later and overlying formations, from the Ohio shore northward to Ballards Reef in Detroit River and the Canard River mouth on the Canadian side of the Detroit.

Over all this anticlinal section, westward of Pelee Island and Kelly's Island, in which lie East Sister, North Harbor, West Sister and Middle Sister Islands and shoals, there is the same surface extension, the Lower Monroe formation. The only exception to be made to this statement is that there is an outer edge of Sylvania Sandrock overlaid by Upper Monroe material along the east and west sides, and an outcropping of rock of earlier age on West Sister Island and in spots east and west and south of it.

19th Mich. Acad. Sci. Rept., 1917.

[1]Oil and Gas in Michigan, Publication 8, Geol. Series 5, Michigan Geol. & Biol. Survey, 1911, p. 371.

A local indication of what the older strata capping the anticline over this area may be holding in reserve is observable in the old Judge Christiancy quarry near Dundee in Monroe County; where the Onondaga (Dundee, Corniferous), beds have been heavily petrolated at some time.

The condition thus indicated may have been, and probably was occasioned by a sideward tilt produced by an uplift about middle Onondaga time, which raised the east side of the field above the surface of the sea from Sandusky Bay northward to Pelee Point and the Amherstburg quarry section. From this sideward tilt the area never fully recovered, a fact evidenced by the narrowness of the Onondaga surface extension in southeastern Michigan and northwestern Ohio (until it changes from a north and south direction) and by a comparison of elevations of the lower Onondaga horizons, which are relatively lower on the Michigan side of the territory in question than on the Ontario side of it.

The west side of the field appears to have sustained local uplift at about the close of Onondaga time. Of this there is evidence in the Sibley neighborhood in Wayne county, where thrusting has been accompanied by crevassing in the later Onondaga beds, beds not laid down in Essex County.

Reasons might be assigned for looking to the east side of the area for gas, the more volatile quantity, and to the west side for oil, preponderatingly. As has been stated the mid-Onondaga east side uplift and westward tilt was only partly balanced up by the later west side uplift. A second reason is the centuries long gradual tilting to southwestward of the continental mass from the direction of James Bay and beyond, which is resulting in Lake Erie waters encroaching upon the land surface over the south and west shores of the lake. (See U. S. War Dept. Coast Chart No. 7.)

Wells in Monroe and Wayne Counties, at Monroe, at Dundee, Trenton, Sibley, Gross Isle, River Rouge, Detroit and Windsor, do not pay, in oil and gas, the cost of putting them down, and for the reason already assigned in the case of the Erie township well, too far down the side, or northward over the nose of the Cincinnati anticline.

Stony Island, possibly Sugar Island and Point Mouillee, Stony Point, the Raisin River Delta, and the islands of north Maumee Bay, together mark a promiseful base-line of operations from the westward over the area delimited; whereas the locality of the mouth of the Canard River in Anderdon Township, Bois Blanc Island, the Detroit River shore in Malden Township, South Colchester and Pelee Island, in Essex County; and the Bass Islands and west of the base of Marble Head Peninsula in Ohio, together mark an east side limit of probability.

If a line A....B be used to represent the state line from Sylvania, Ohio, eastward into Lake Erie; and a curved line C....D the surface of the Trenton—for example; and E....F the Potter well, 1,555 feet to and 112 feet into the Trenton in Erie Township, Monroe County, Michigan; then it is shown how, located as it is, that well penetrated only the upper or outer strata of the Trenton and trends away from the possible reservoir of the arch of the anticline, the angle at G being obtuse.

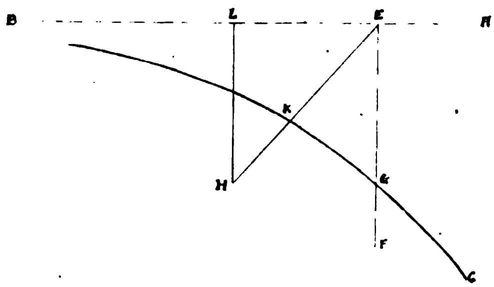



Figure 3. Diagram of geological conditions with reference to oil wells sunk in the region studied.

To penetrate the Trenton strata directly from point E the drill should follow the line E....H to take the Trenton surface at right angles at K, and penetrate the depth of possible supply: the logical meaning of which is a well at L, (in relation to point E) and preferably at some point along the line L....B, on the west shoulder of the anticline, or along L....B projected, on the east shoulder. The line E....F, however, illustrates the relative position of each and every well that has been put down in search of oil on the Michigan side of the field and, in a less degree only, on the Ontario side of it. None but lateral tests have been made, and most of these remote.

Unfortunately the only land surfaces within the enclosed area are the Sister Islands, East, Middle and West, North Harbor, the Hen and Chicken Islands, and the associated banks and shoals.

### EXAMINATION OF THE FIELD BY CROSS SECTION.

A Ballards Reef east and west section of the northern part of the field under review would show these surface extensions in order, westward of the reef: Lower Monroe for a short distance; Sylvania sandstone over at least a part of Grosse Isle; Upper Monroe on westward part of Grosse Isle, throughout its entire length and over nearly all the Trenton Channel of Detroit River; Anderdon limestone beds all about the outer edge of the Sibley quarry area from about the River Road westward, probably reaching the west bank of the Trenton Channel, opposite the Church Company's dairy barn well, and possibly reaching

over to the east bank of the channel at this point, from evidence of Sibley cores; a showing of Oriskany sandstone at both the base and the surface of the Anderdon Beds, this heavy silication embracing the characteristic Anderdon fossil-bed and invading the dolomitic limestone base of the overlying Onondaga.

Eastward of Ballards Reef: Lower Monroe, Sylvania—pumping up in one water well on the Stevenson Stock Farm; Anderdon limestone beds probably, and Onondaga, in the same order as on the west side of the reef, but in reverse direction.

A section from Elliotts Point, Essex County, southwestward to the Huron River, shows Lower Monroe over the whole distance from inshore on the Essex side to the inner mouth of the Huron; and northeast of the point, Sylvania, Upper Monroe, and a shallow Anderdon Beds-filled trough in the Monroe.

A section from the Huron River southeastward to Pelee Island would show Lower Monroe over the entire Detroit River mouth distance, until the later formations would be crossed in ascending order off the west side of Pelee Island, which is itself Onondaga.

A section east and west from the south end of Pelee Island to the town of Sylvania would traverse these in reverse order again, developing Oriskany and Anderdon doubtless, Upper Monroe, Sylvania, Lower Monroe, Clinton and Niagara probably, Salina and Lower Monroe on West Sister Island, possibly Clinton and Niagara again, and again Lower Monroe, until the Sandrock is again reached at Sylvania.

The Trenton rock, popularly regarded as the natural cap of mineral oil deposits since it is the containing cap in so many oil areas, is covered everywhere throughout the whole triangular territory now being theoretically exploited, by newer strata.

All the evidence invites to the trying out of the Michigan-Ohio-Ontario part of the west end of Lake Erie, from Ballards Reef south to a base line about six townships in length, connecting the point where the Michigan-Ohio state line comes out on Maumee Bay, and (say) Danbury on Sandusky Bay.

The northern part of this territory may be thought to be unpromising because of its very narrow width and also its remoteness from the known broad tested field in Ohio. There is this favorable indication, however, *a series of minor folds* across the general trend of the underlying Cincinnati arch.

Ballards Reef in Wayne County, and the mouth of the Canard River in Essex County, mark one upward fold. The Limekiln Crossing (Essex) and Stony Island (Wayne) together mark a second. The upper half of Bois Blanc Island and westward beyond the international boundary a

third. And across the greater part of the entire width of the Detroit River, clear of the foot of Bois Blanc and Sugar Islands a fourth.

The same condition prevails off shore in Ohio waters. Also a showing of oil was obtained in the Trenton, in November, 1914, at the Amherstburg quarry in Anderdon Township, Essex County.

There is also *a minor synclinal trough* on both east and west sides of the central and east side Detroit River Lower Monroe area, as was proven with the core-drill in surveys of 1910, 1911 and 1912.

### SUPPORTING EVIDENCE PRESENTED IN THE TREND AND CHARACTER OF THE ESSEX-KENT-LAMBTON-PORT HURON FIELD.

It is interesting to observe that a line drawn from beyond Lima, Ohio, past Findlay, N. 40° E., and projected in the same general direction, traverses the central part of the Ohio oil field, passes close by on the west side of the Pelee Island oil field, crosses the Kingsville-Leamington gas field, the Tilbury oil field and the Romney gas field, the Chatham oil field, and the old Petrolia oil field.

Along this surface, beyond the block-faulted, Lake Erie Islands part of the distance, the present rock elevations are lower toward the north. Overtop of the Lower Monroe are added on in order the Sylvania Sandrock, Upper Monroe, Anderdon limestone beds probably, the Onondaga limestone, the Hamilton rock, and the overlying shales. It thus becomes evident that whatever of local Cincinnati anticline there may have been in Ordovician-Silurian time, branching off into Canada (as Michigan and Ohio geologists for the most part assume) there is small room for it now, unless it lies deep down.

It is not, therefore, a matter of surprise that gas and oil have escaped by the Lake Erie faults into the strata of higher horizon and relatively lower elevation in the southwestern Ontario fields.

In all of these fields, as in one connecting field, the oil and gas appear to be held in the rock of newer formations overlying the deeper parts of that broad Silurian syncline which carries, exposed in surface extension along its northern side, the Onondaga (Corniferous), the Hamilton and the associated shales, across Cheboygan, Presque Isle and Alpena Counties in Michigan; across Bruce, Huron, Perth and Oxford counties in Ontario, in southeast direction; thence east by south into New York state about Buffalo.

Doubtless the whole of the western Ontario oil and gas area thus far investigated, Pelee Island, Kingsville-Leamington, Tilbury, Romney, Chatham, and Petrolia (and also the Port Huron field in Michigan) are one continuous overflow field receiving its supply from a main reservoir, the pressure in which is relieved by this outflow through disturbed strata.

It follows, if these deductions be correctly drawn, that west of Port Huron and toward the centre of the state there is but little reasonable expectation of oil or gas in paying quantity, since the strata dip rapidly westward, a dip which may be illustrated by the comparative statement that the salt horizon at the foot of Saginaw Bay is 2,200 feet lower than it is in Goderich harbor on the opposite side of Lake Huron.

The cause of change of direction of the field from N. 40° E. across Ohio and Ontario to Chatham and beyond to northwesterly, by way of Oil Springs and Oil City and Port Huron, was unquestionably the movement which produced the uplifted exposure of Hamilton rock across the northeast corner of Lambton County from Arkona to Thedford and the shales at Kettle Point.

### FURTHER EVIDENCE SUSTAINING THE ARGUMENT.

If, by earth movement, or a series of movements somewhat violent in character, a major anticlinal reservoir is faulted laterally, gas and oil will escape and be forced by the dynamic of the reservoir into higher strata adjacent.

If the line of fault be continuous across country the escape of gas and oil from the reservoir is facilitated.

If the strata into which the oil flows be laid down in a major syncline, as from Lake Erie across to Lake Huron and northward, "lakes" and "pools" of oil and "pockets" and reservoirs of gas will result, deposited according to the natural inequalities of the synclinal floor and of the overlying strata, inequalities probably emphasized by disturbance. Crevices, unless on a major scale, are nearly always capped by beds that overly, whether by deposit or by readjustment, or capped and plugged by glacial detritus. Consequently both gas and oil are confined and forced into the interspaces of the strata. Pressure from behind, both hydrostatic pressure and the pressure of gas, will continue to force both oil and gas further afield, even beyond the reach of the fault line. And always the tendency will be for the escaping substances to find their way into strata of ascending horizon and to higher elevations.

As an oil field is pumped and the oil pressure decreases because the supply begins to be exhausted, if there be a suitable reservoir left thus to receive and retain the gas the supply and pressure of gas will be increased. This for two reasons: gas rises naturally from the oil and, as the more volatile substance, it finds freer vent from the main reservoir.

Accordingly, in addition to these peculiarities in the southwestern Ontario field already read as lateral phenomena, there is this series of facts to be considered:

Oil flows from about 155 feet below mean tide level on Pelee Island, or from some 700 feet below the surface of the Onondaga. In the Tilbury-Romney field oil is obtained at about 187 feet below tide, or some 600 feet below the Onondaga surface; whereas in Romney gas flows copiously from the Onondaga[2]. In the Chatham field oil comes from about 108 feet *above* mean tide level, and from something over 40 feet in the Onondaga. In the Petrolia field the oil horizon is about 202 feet AT. and about 65 feet in the Onondaga. At Sarnia, flanked by the Hamilton uplift at Thedford, and with the Michigan basin in front, the gas horizon drops to about 190 feet AT., but, from the shale depths at this point, this would appear to be up in the rock of the Hamilton formation.

It is of interest to note that, whereas in Romney Township the very limited flow of oil is from small pools, in Tilbury alongside the greatly enhanced supply is held in crevices. And the parties chiefly interested commercially state that in Romney, as the Tilbury and Romney and Chatham oil continued to be drawn off, the pressure of gas became measurably greater.

The new discovery of gas at 1,800 feet in the Petrolia field, at Oil Springs, does not affect the argument except to lend it support. The oil in this field is obtained at from 300 to 400 feet from the surface, and some 65 feet in the Corniferous (Onondada of New York state). If strong flow of gas be obtained from below this at 1,800 feet, or at any depth whatever below, it follows that the oil at the upper horizon must be an overflow supply from some other source than that of the lower gas.

At precisely the same time at which the Pelee Island and Amherstburg quarry Onondaga sustained uplift in Essex County on the northeast shoulder of the Cincinnati insular dome, the same lower Onondaga beds were disturbed on the north shore of the Ontario arm of the Devonian sea. This is shown in the Horse Shoe quarry at St. Marys, Perth County, where there is a crevice across the field. On one side of this break are the same lower Onondaga beds as were laid down in Essex County in the parts uplifted. But on the other side of the crevice, no fault having developed from the break, the later Onondaga strata begin at once to be added on, and with much sharper dip. The adjacent hard, brittle Anderdon Beds limestone on the north side of the town of St. Marys is heavily faulted, just as it is shattered along the east bank of the Anderdon-Malden trough.

Add to this evidence the corresponding fact that the rock surface along the Lake Erie shore of Elgin, Kent and Essex Counties, has a greater elevation than the extension north and south of it, and but one

[2]So stated by the operating companies.

conclusion can be drawn. That conclusion is that *a barrier has been lifted up* dividing the late Devonian and subsequent seas of Michigan and the southwestern waterfront counties of Ontario, from the seas of the same period and periods which built up the greater remaining part of the present Lake Erie bed material, the western part of Pennsylvania, southern New York, the western part of Virginia, the eastern third of Kentucky, and northern Tennessee.

The bearing of this upon the oil question is thus stated: Any possible segregated overflow or other supply of oil there may have been east of of this barrier and between it and the uplift across the Niagara peninsula, would naturally find its way down the incline of the basin which has for its center the Ohio-Virginia coal measures.

The absence of oil in the Cayuga and Port Colborne fields of gas supports this conclusion.

It may possibly be that deep down under all the disturbed area of the west end of Lake Erie and the associated counties in Ontario there is a major anticline. In such case there is not only one but a second promising field awaiting the drill, of which, as in the case of the first, merely the outer edge has been essayed.

Chalk River, Ontario, February, 1917.

# SOME NEW THERMO-OPTICAL OBSERVATIONS ON GYPSUM AND GLAUBERITE.

BY E. H. KRAUS AND ALBERT B. PECK.

## INTRODUCTION.

Several years ago a number of articles were published from this laboratory dealing with the changes in the size of the angle of the optic axes with temperature and also with the determination of the temperature of uniaxiality of gypsum[1] and glauberite[2].

In the first paper dealing with gypsum a comparatively large oil bath was used, the source of heat being two Bunsen burners. While the apparatus was somewhat crude in character, it nevertheless permitted extensive observations to be made with a considerable degree of accuracy on the variation in the size of the optic angle with temperatures between 18.2° C and 182.5° C. It was definitely determined that uniaxiality for sodium light, the only type of monochromatic light employed, occurs in the neighborhood of 90° C. Observations were also made by heating gypsum in an air bath and it was shown that the greatly divergent results concerning uniaxiality temperatures obtained by previous investigators were due to too rapid heating and the use of air baths. In the second article the study of the uniaxiality temperatures for gypsum for a large number of wave lengths was made employing a new heating apparatus consisting of a small glass container for the oil which was heated by an electric resistance coil. Light of various wave lengths was obtained by the use of a Fuess monochromator. The curve showing the temperatures of uniaxiality indicated clearly that the maximum temperature for uniaxiality occurs when light having a wave length of about 560$\mu\mu$ is used. In making the observations for gypsum recorded in these two papers, plates prepared by Steeg und Reuter, Homburg v. d. Höhe, were employed. Unfortunately the localities from which the material was obtained were not known. It was therefore thought advisable to repeat the second investigation using sections from several known localities. The first portion of this paper, therefore, gives some new observations on the uniaxiality temperatures of gypsum from Ellsworth, Ohio; Eisleben, Germany; and Cianciana, Sicily.

19th Mich. Acad. Sci. Rept., 1917.

[1]Neues Jahrbuch fuer Mineralogie, Geologie und Palaeontologie, 1912, Vol. 1, p. 123-46, and Centralblatt fuer Mineralogie, Geologie, und Palaeontologie, 1914, p. 356-9.
[2]Zeitschrift fuer Krystallographie, 1913, Vol. 52, p. 321-6.

In 1918 observations on the change of the optic angle of glauberite were published but for only two types of monochromatic light, lithium and sodium. In the present paper new observations are given on the variation in the size of the optic angle of glauberite for light of several different wave lengths and on the temperatures for uniaxiality for wave lengths between $511\mu\mu$ and $687\mu\mu$.

### APPARATUS.

The apparatus used in these new experiments consisted of the axial angle apparatus and the large metallic oil bath of 150 c.c. capacity employed in the original experiments in 1911. This bath was, however, heated by a larger resistance coil than that employed in the experiments reported in the second paper. The heating apparatus consists essentially of a tile plate about 20 cm. square on the under side of which are fastened a series of small resistance coils. The oil bath, containing the section to be investigated and into which the bulbs of the two long thermometers penetrate, and the heating plate are all enclosed in an asbestos box, the sides of which are easily removable. Experience has shown that more accurate and consistent results are obtained when a larger oil bath is employed than when one of smaller capacity such as was described in the second paper is used. An oil bath of comparatively large capacity permits a more gradual increase or decrease of temperature to take place as also an easier maintenance of a constant temperature. These factors are highly desirable inasmuch as gypsum responds more readily to slight changes in temperature than does the mercury in the thermometers. By placing several secondary resistances in the circuit, the temperature within the oil bath could be very easily regulated. The thermometers permitted readings to be made to 0.1° C. The results given in the various tables have all been corrected and take into consideration the temperature of the room surrounding the apparatus, the temperature in the asbestos box surrounding the oil bath, and the length of the thermometer tubes. Curves have been developed from such corrected observations.

Monochromatic light was obtained from a Fuess monochromator using as the original source of light a small hand-feed, direct current arc light. The monochromator was first carefully adjusted for sodium and lithium lights so as to insure accurate readings. This instrument is exceptionally useful in the determination of uniaxiality temperatures as a simple rotation of the drum allows exceedingly rapid changes in the character of the light supplied to be made. In fact, an apparatus of this type is indispensable for observations involving the use of

different types of monochromatic light at the same temperature or at temperatures which are changing slowly.

### UNIAXIALITY OF GYPSUM.

Carefully oriented sections of colorless, transparent gypsum from the following three localities—Ellsworth, Ohio; Eisleben, Germany; and Cianciana, Sicily—were prepared and observations made for the temperatures at which uniaxiality is to be noted for wave lengths ranging from 435 $\mu\mu$ to 702 $\mu\mu$. These observations are given in the following table:

Table 1.

Temperature of Uniaxiality for Gypsum.

| Wave Length | Ells-worth | Eis-leben | Cian-ciana | Wave Length | Ells-worth | Eis-leben | Cian-ciana |
|---|---|---|---|---|---|---|---|
| 435 $\mu\mu$ | | 87.60°C | | 545 $\mu\mu$ | | 90.95°C | |
| 443 | | 87.95 | | 551 | | 90.95 | |
| 445 | | 88.00 | | 554 | | | 91.25°C |
| 450 | 88.25°C | 88.30 | | 555 | | 91.10 | |
| 451 | | 88.35 | | 560 | 91.35°C | 91.25 | |
| 452 | | | 88.20°C | 564 | | | 91.20 |
| 458 | 88.65 | | | 568 | | 91.25 | |
| 459 | | 88.40 | | 575 | 91.30 | 91.15 | |
| 460 | 88.90 | | | 580 | | | 91.00 |
| 461 | | | 88.55 | 593 | | | 90.95 |
| 465 | | 88.98 | 89.12 | 594 | 91.00 | | |
| 467 | 88.90 | | | 600 | | 90.60 | |
| 470 | | 89.20 | | 609 | 91.15 | | |
| 471 | 89.15 | | | 611 | | | 90.75 |
| 472 | | 89.45 | | 613 | | 90.55 | |
| 475 | | | 89.45 | 616 | | 90.45 | |
| 478 | 89.45 | 89.65 | | 617 | | 90.40 | |
| 480 | | 89.70 | | 620 | 90.80 | | |
| 481 | 89.70 | | | 623 | | 90.35 | |
| 485 | | | 90.05 | 624 | | | 90.50 |
| 486 | 89.80 | | | 629 | 90.60 | | |
| 487 | | | 90.25 | 631 | | 90.15 | |
| 488 | 90.15 | 89.90 | | 634 | 90.55 | | |
| 494 | | | 90.45 | 635 | 90.50 | | |
| 495 | 90.30 | | | 637 | | | 90.15 |
| 499 | | | 90.60 | 640 | 90.30 | 89.95 | |
| 500 | | 90.25 | | 643 | 90.15 | | |
| 507 | | 90.50 | | 652 | | 89.40 | |
| 508 | 90.45 | | | 656 | 89.80 | | 90.02 |
| 511 | 90.65 | 90.65 | | 660 | 89.55 | | |
| 515 | | | 90.95 | 663 | | 89.35 | |
| 519 | 90.90 | | | 664 | | | 89.95 |
| 520 | | 90.70 | | 667 | | 89.25 | |
| 525 | | | 91.00 | 670 | | 89.27 | |
| 529 | | | 91.15 | 676 | 89.25 | | |
| 531 | 90.90 | | | 680 | | 89.10 | 89.80 |
| 538 | | 90.90 | | 686 | | 88.95 | 89.40 |
| 544 | 91.10 | | | 702 | | 88.75 | |

Plate II shows the uniaxiality curve resulting from these observations. While the observations for these sections are all of the same order, nevertheless those for the Sicilian section seem to be a trifle higher than

for the other two. These variations were, however, only in one case as great as 0.7° C and usually less than 0.25° C, which may be considered as being well within the limits of error. The uniaxiality curve is of the same general character as the one described in 1914, although the uniaxiality temperatures for any given wave length are somewhat higher than formerly recorded. Thus, we are able to indicate that the highest uniaxiality temperature is about 91.3° C for 560$\mu\mu$ which corresponds to 89.4° C for the same wave length of the earlier report. These new observations are in fuller accord with those published by Hutchinson and Tutton[3] and for reasons previously given are to be considered more accurate than the earlier results. It will be noted from Plate II that for light with the longer wave lengths, i. e. above 600$\mu\mu$, there is a greater divergence in the observations than for light of shorter wave lengths. This is due to the fact that the hyperbolic brushes of the biaxial figures for light of the longer wave lengths are very broad and, hence, it is more difficult to determine when the brushes are exactly crossed thus forming the uniaxial figure for the wave length under consideration. Some of the more important uniaxiality temperatures, as determined from the curve, are as follows:

| | | | | | |
|---|---|---|---|---|---|
| 465 $\mu\mu$ | | 89.02°C | 589 $\mu\mu$ | (D line) | 91.12°C |
| 486 | (F line) | 89.90 | 656 | (C line) | 89.82 |
| 527 | (E line) | 91.02 | 670 | | 89.47 |
| 560 | | 91.27 | 687 | (B line) | 89.02 |

VARIATION OF THE ANGLE OF THE OPTIC AXES OF GLAUBERITE WITH TEMPERATURE.

In 1913 observations on the variation of the optic angle of glauberite with temperature were published for lithium and sodium lights. It was clearly established at that time that the uniaxiality points for these two types of light are considerably lower than had been previously determined by Laspeyres[4]. In the present study, measurements of the variation in the angle of the optic axes for different wave lengths were undertaken employing the oil bath of larger capacity and the Fuess monochromator. The section was prepared from material from Villa Rubia, Spain, which was not entirely homogeneous. This was clearly observable under the miscroscope. There were also slight variations to be noted in the observations made in different parts of the section. Kozu[5] has recently called attention to similar variations in certain feldspars studied by him. Our observations are recorded in the following table:

[3]Mineralogical Magazine, 1912, Vol. 16, p. 257-63.
[4]Zeitschrift fuer Krystallographie, 1877, Vol. 1, p. 529-546.
[5]Mineralogical Magazine, 1916, Vol. 17, p. 237-58.

Table 2.

Size of the Optic Angle of Glauberite for Various Wave Lengths at Different Temperatures.

| T°C | 465$\mu\mu$ |
|---|---|
| 25.5 | 3°38′ |
| 30.0 | 5 6 |
| 35.0 | 6 0 |
| 41.7 | 6 57 |
| 58.5 | 10 8 |
| 62.2 | 10 44 |
| 65.4 | 12 1 |
| 76.0 | 12 48 |
| 96.0 | 15 2 |

| T°C | 486$\mu\mu$ |
|---|---|
| 35.5 | 4°31′ |
| 41.0 | 5 9 |
| 45.5 | 6 58 |
| 57.0 | 8 56 |
| 61.3 | 9 54 |
| 76.5 | 12 5 |
| 86.5 | 13 10 |
| 96.2 | 14 17 |

| T°C | 527$\mu\mu$ |
|---|---|
| 44.7 | 4°37′ |
| 56.0 | 7 35 |
| 60.3 | 7 23 |
| 67.0 | 9 48 |
| 77.0 | 11 3 |
| 86.7 | 11 52 |
| 96.6 | 12 58 |

| T°C | 589$\mu\mu$ |
|---|---|
| 25.65 | 5°28′ |
| 29.85 | 3 52 |
| 52.0 | 3 36 |
| 55.0 | 4 55 |
| 59.6 | 5 58 |
| 68.0 | 8 6 |
| 77.5 | 9 22 |
| 87.1 | 10 56 |
| 97.0 | 12 11 |

| T°C | 656$\mu\mu$ |
|---|---|
| 25.65 | 7° 5′ |
| 30.15 | 6 20 |
| 39.4 | 5 16 |
| 69.0 | 6 25 |
| 78.5 | 8 6 |
| 87.6 | 9 41 |
| 97.5 | 11 23 |

| T°C | 670$\mu\mu$ |
|---|---|
| 25.65 | 7°50′ |
| 30.45 | 7 0 |
| 34.15 | 6 53 |
| 39.7 | 5 41 |
| 70.0 | 6 22 |
| 79.0 | 8 6 |
| 88.0 | 8 52 |
| 97.8 | 10 37 |

| T°C | 687$\mu\mu$ |
|---|---|
| 25.65 | 8° 8′ |
| 30.65 | 7 12 |
| 34.15 | 6 50 |
| 41.5 | 5 31 |
| 71.0 | 6 0 |
| 79.5 | 7 12 |
| 88.5 | 8 7 |
| 98.0 | 10 45 |

Plate III shows full curves between 25° C and 98° C for 589, 656, and 670$\mu\mu$ and partial curves for 465, 486, and 527$\mu\mu$. The full curves correspond in general to those published earlier although the observed uniaxiality points are slightly lower. This means that the angles below uniaxiality are slightly smaller and those above the uniaxiality point are slightly larger for any given temperature than those previously recorded. The agreement between the new and the older observations on glauberite is greater than in the case of gypsum, for both series were made by using the same oil bath, namely one with a capacity of about 150 c.c., and as uniaxiality takes place at lower temperatures, constancy of temperature can be better maintained.

### UNIAXIALITY TEMPERATURES OF GLAUBERITE.

Several series of observations were made of the temperatures at which uniaxiality is to be observed for light ranging from 511$\mu\mu$ to 687$\mu\mu$.

These temperatures, as given in the following table, represent the average of three series of readings and from them the uniaxiality curve of Plate IV has been drawn.

Table 3.

Uniaxiality Temperatures of Glauberite.

| | | | |
|---|---|---|---|
| 511 $\mu\mu$ | 27.0°C | 592 $\mu\mu$ | 41.0°C |
| 516 | 28.0 | 609 | 42.0 |
| 523 | 29.0 | 611 | 43.0 |
| 528 | 30.0 | 619 | 44.0 |
| 534 | 31.0 | 626 | 45.0 |
| 540 | 32.0 | 633 | 46.0 |
| 546 | 33.0 | 639 | 47.0 |
| 551 | 34.0 | 644 | 48.0 |
| 556 | 35.0 | 651 | 49.0 |
| 560 | 36.0 | 659 | 50.0 |
| 566 | 37.0 | 670 | 52.8 |
| 572 | 38.0 | 672 | 53.0 |
| 578 | 39.0 | 687 | 54.1 |
| 584 | 40.0 | | |

The uniaxiality temperatures for six important wave lengths as developed from the curve follow:

| | | | | |
|---|---|---|---|---|
| 527 $\mu\mu$ | (E line) | 29.8°C | 656 $\mu\mu$ | 48.6°C |
| 560 | | 35.5 | 670 | 51.6 |
| 589 | (D line) | 40.6 | 687 (B line) | 54.1 |

The curve shows an unexpected break at about 600 $\mu\mu$ for it was thought that a straight line curve should result. This change in direction may possibly be due to several factors. First, as was noted in the case of gypsum above, the hyperbolic brushes are very much broader for light above 600 $\mu\mu$ than for that below. This obviously makes accurate determination of the exact temperature at which uniaxiality takes place extremely difficult. Second, the observations plotted in Plate IV are the average of three sets of readings made from different portions of the same section. As already indicated, slight variations in the character of the section could easily be recognized under the microscope and these may account to some extent at least for the break in the curve. A third reason may be that at a temperature of about 42° C some slight change in chemical composition may take place. Of the three possible explanations, the first undoubtedly is to be considered as the most probable.

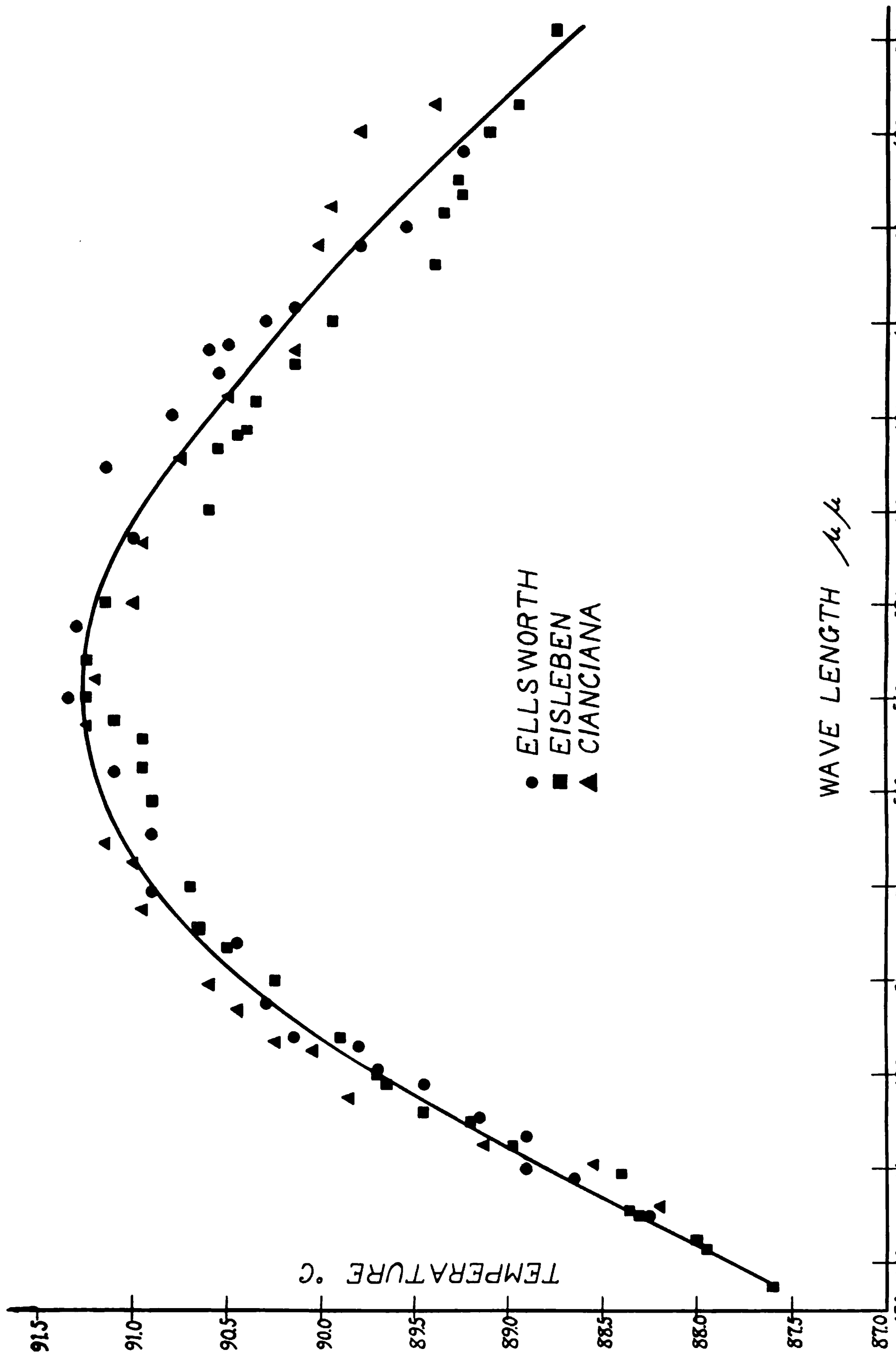
Mineralogical Laboratory, University of Michigan.

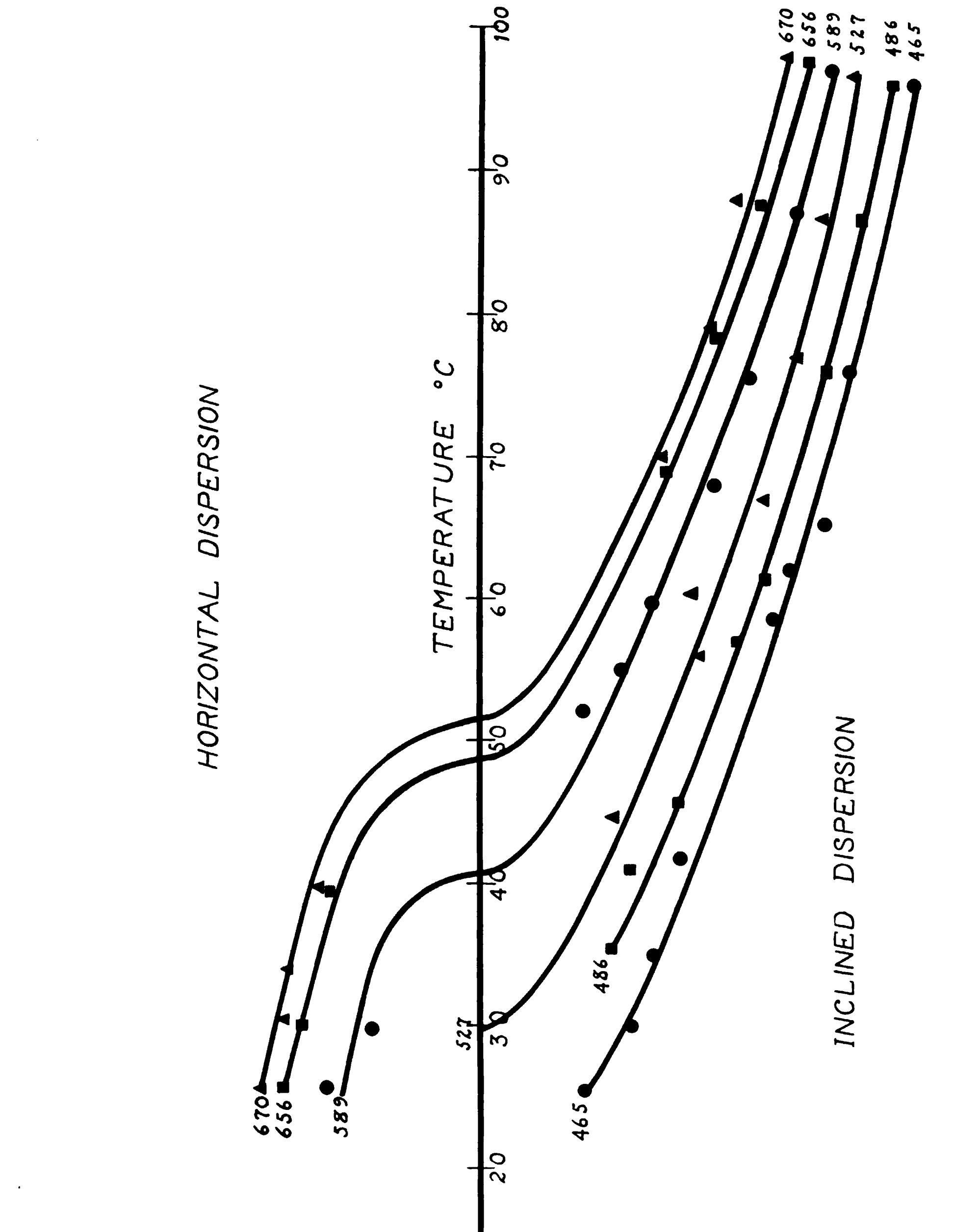
## LEGENDS.

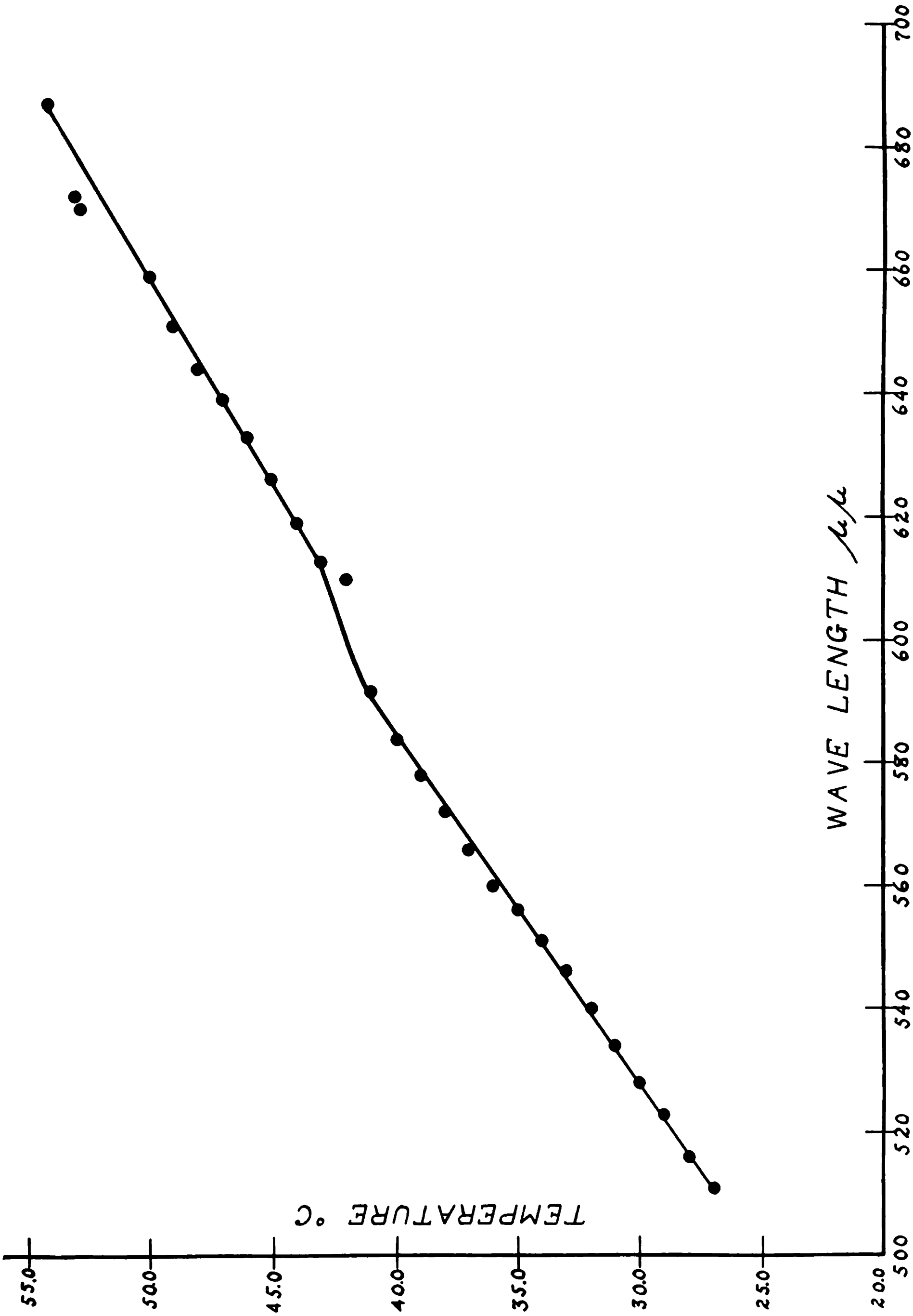
Plate II. Change in temperature of uniaxiality in gypsum for various wave-lengths.

Plate III. Change in the apparent optical angle in oil of glauberite for various wave-lengths and temperatures.

Plate IV. Change in temperature of uniaxiality in glauberite for various wave-lengths.


TEMPERATURE °C
91.5
91.0
90.5
90.0
89.5
89.0
88.5
88.0
87.5
87.0
WAVE LENGTH μμ
430
440
460
480
500
520
540
560
580
600
620
640
660
680
700
ELLSWORTH
EISLEBEN
CIANCIANA


HORIZONTAL DISPERSION
TEMPERATURE °C
INCLINED DISPERSION
OPTIC ANGLE 2Ha
670
656
589
527
486
465


WAVE LENGTH μμ
TEMPERATURE °C
500
520
540
560
580
600
620
640
660
680
700
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0

# GLACIAL LAKES AND THEIR CORRELATIVE ICE-BORDERS IN THE SUPERIOR BASIN.

BY FRANK LEVERETT.

(Abstract.)

The paper deals only with the final recession of the ice from the Superior Basin, and from what appears to be the Port Huron morainic system in that basin. There seems to have been considerable ice recession preceding the Port Huron readvance with a corresponding enlargement of glacial lakes in this basin as well as in the Huron and Michigan basins. The readvance overrode and completely obliterated the glacial lake in the western Superior basin. There was probably also an interglacial lake in the Superior basin following the Illinoian glaciation.

The latest lobe of ice that occupied the Superior basin was part of the Labrador ice sheet. On melting away it made a northeastward recession from the west end of the basin past the Keweenaw Peninsula. At the same time there was northward recession of the ice border from the Michigan and Huron basins across the eastern end of the Northern Peninsula into the eastern part of the Superior basin. The latest hold of the ice on the soil of Michigan was in the part of the shore of Lake Superior between the Huron Mountains and Whitefish Point.

The ponding of glacial waters at the west end of the Superior basin was at first in a chain of small lakes, separated by higher unsubmerged areas, which extended to the border of the ice. Lake Nemadji, at the extreme west end of the Superior Basin, discharged past Moose Lake, Minnesota, to Kettle River and thence to the St. Croix and Mississippi Rivers. Lake Brule occupied a narrow strip along the Brule valley and discharged southward to the St. Croix River. The next lake to the east covered a lowland south of Ashland and will be termed Lake Ashland. This lake discharged westward across the Bayfield Peninsula, just south of Iron River, Wisconsin, to Lake Brule. The northern part of the peninsula was still covered by the ice sheet. Still farther east was another lake covering part of the Ontonagon drainage basin in the western part of the Northern Peninsula of Michigan, and called Lake Ontonagon. This discharged westward into Lake Ashland near Saxon, Wisconsin. At this time the ice still covered the plain between the Copper Range and Lake Superior.

19th Mich. Acad. Sci. Rept., 1917.

With the melting away of the ice from the Bayfield Peninsula and other prominent parts of the district south of Lake Superior, the ponded waters all became merged into a single body of water, Lake Duluth, which had the level of Lake Brule, and utilized its outlet to the St. Croix River and Mississippi. This outlet channel has a floor about 420 feet above Lake Superior at the present summit swamp, and beaches turning into it are still higher, for the outlet was deepened by the discharge of the lake waters through it. The ice seems to have melted from the Keweenaw Peninsula soon after Lake Duluth had been formed, for strong beaches of Lake Duluth are found on the Keweenaw Peninsula as far northeast as Calumet.

The ice held its front on the Huron Mountains for a relatively long time, and thus formed the eastern limit of Lake Duluth. With the recession of the ice border down the east slope of the Huron Mountains the glacial waters soon found a passage around the edge of the ice southward and discharged into Lake Algonquin, which by that time was occupying the Michigan as well as the Huron Basin. The recession from the Huron Mountains opened lower and lower passages until the lake in the western part of the Superior Basin was drawn down to the level of Lake Algonquin and became a part of that lake.

The lowering of the lake waters from the Algonquin to the Nipissing level occurred when the Ottawa Valley became freed from ice. This seems to have taken place soon after the waters in the western end of the Superior Basin were lowered to Algonquin level, for the Algonquin beach is very weak in the western Superior Basin. It is not as yet known whether the ice had entirely disappeared from the eastern part of the Superior Basin before the Ottawa Valley was freed from ice. There is thus a possibility that part of the northern and eastern border of the Superior Basin does not have an Algonquin beach. So far as the Michigan part of the Lake Superior Basin is concerned, there was complete disappearance of the ice sheet prior to the Nipissing stage. The Nipissing shore is strong all along the south shore of Lake Superior as far west as it stands above the level of Lake Superior. West from the Bayfield Peninsula the Nipissing shore is below Lake Superior level.

Ann Arbor, Mich.

# AGRICULTURE.

# EUGENICS AND THE AGRICULTURAL COMMUNITY.*

OTTO C. GLASER.

I am not an agriculturist, much less an investigator in this field. However, I have a full share of the layman's interest and sympathy, for it requires no further demonstration to convince me that the stability of the nation depends directly and indirectly on the agricultural community.

Not only is this community the source of our food, it is also in a large measure, the source of our men. As has been truly said, "The country produces men, the city consumes them." Hence the eugenic problem.

The type of man who goes to the city is apt to be ambitious, enterprising and alert. Yet the improvements in agricultural communities, the increase of possibilities in country life now demand more than ever the very characteristics which hitherto have found their natural market in the city. The time seems past when agriculture can make use of the less alert, the less ambitious, and the drain which has taken place and which is still continuing, though with some abatement, is full of danger. It leads ultimately to the concentration in agricultural communities of the unprogressive traits. Conditions similar to those on islands have already come about in numerous places and have resulted in too much intermarriage among a small group of families. In fact there are towns where nearly everyone is related to everyone else and one hears only two or three family names.

From the eugenic standpoint, such towns are as truly islands as though surrounded by water. The barrier in these cases, however, is a group of restrictions social and economic in nature and differential in effect. Modern arts are breaking these down, but unfortunately the returning tide of men is not yet sufficiently strong to offset the harm that has been done.

For this reason it seems desirable to the student of heredity to foster the eugenic ideal within the agricultural community. By their very contacts with nature such communities are easily capable of understanding the principles involved. The value of good stock is to them no novelty. The methods by which its value can be retained or even enhanced are in constant practice. There are good grounds then for expecting success here in the propagation of eugenical measures.

19th Mich. Acad. Sci. Rept., 1917.
*Abstract.

Of the positive methods which suggest themselves, general education in the laws of natural inheritance and other matters of eugenic importance, should be mentioned first. Such education is always practicable. A second influence which may be brought to bear is that of the Eugenics Registry. The success of the Registry must also depend chiefly on its capacity to influence personal behavior. Its aim is to encourage the individual to make an inventory of socially important traits and tendencies known to be hereditary. The blanks on which these traits are charted involve several generations and a full constellation of immediate relatives. The mere process of filling them out is educative and altogether likely to convince the person so engaged that individual characteristics do not come from a clear sky. Moreover, the presence of such blanks in one household is apt to create a demand for them in others.

In this way we may hope gradually to bring about a more serious attitude toward human matings—an attitude in no wise likely to interfere with personal liberty, but on the contrary calculated in the long run to insure this. To reduce the frequency of disgenic marriages and their unfortunate chain of consequences will increase the liberty of the individual and free the community as a whole from the necessity of caring for so large a share of incompetents.

University of Michigan.

# RURAL SANITATION.

BY WARD GILTNER.

It will not be worth our while to enter upon a lengthy discussion of the subject of rural sanitation unless there exists a real need for better sanitary conditions in rural communities. That such a need exists is attested by the recent widespread interest in the matter by men and women in various walks of life. To fully appreciate rural conditions as regards sanitation, one must have had broad experience in isolated rural life followed or preceded by the contrast furnished by well organized community life and to make one's perspective truer some time must have been spent also in the congested city districts. To such a one there comes the realization of the certainty that, while the country should and may be the ideal place in which to live and to rear a family, it frequently isn't. It is said that "God made the country, man made the city and the devil made the small town." We are finding considerable evidence of late to substantiate a belief that man has done at times the best job.

The need for the dissemination of knowledge on sanitation in rural communities is great and pressing, but I am afraid the need is greater than the demand.

That the country at its best approaches nearest the ideal for life I have no doubt and that we will be able to put it at its best by persistence and patience I have equally little doubt. The selection of the proper material to present and the selection of the method to employ and the men to present it and employ it is a great problem. It is not an easy task to convince the rural housewife that physical or mental inefficiency, disease or death in her precious household are largely preventable and exist only because her ignorance, unbelief or inactivity permit; or to show her worthy husband that the welfare of the livestock in his barns is a matter quite within his control and that the presence or absence of infectious diseases in his stock is an index of his intelligence and spirit of progress. It will require a great deal of tact to get even a hearing, to say nothing of accomplishing the aim in view.

Before launching out on a missionary campaign designed to carry the gospel of better, safer living to the good sturdy country people, it is well to pause and analyze the gospel that is to be preached. Let us see if our doctrine is sound and assure ourselves that our precepts can be

19th Mich. Acad. Sci. Rept., 1917.

put into practice and when practiced that they will convert the deplorable conditions painted by us into a veritable heaven on earth. It might be well to draw the picture of present conditions with the pen of the mechanical draftsman and let the artist paint in glowing colors the results derived from our campaign, in order that the contrast may redound favorably to the work of improvement. While over enthusiasm and rash promises must be avoided, I am sure that we know many things about sanitation that are not now generally known and appreciated in the majority of rural families, that we could be of real assistance to the farmer's family in bettering his condition hygienically and aesthetically without revolutionizing his method of life and that the proper appeal to the country people would result in these gradual and beneficial changes. At the same time it will be necessary to constantly, and even speedily, acquire new facts concerning the best methods of applying the principles of sanitary science to the peculiar rural conditions.

The principles of Sanitary Science apply in all cases. Those principles, based on the physiologic requirements of the living animal body, have been fairly well worked out. It is quite true that much has yet to be learned—and unlearned for that matter—concerning the fundamentals of right living, but we may surely fight the good fight with courage, using only the armor and weapons now at our disposal. We cannot help but feel that the application of these great principles to the peculiar isolated rural conditions is the difficult task.

In attempting to correct the determined evils surrounding the farmer's life we will find that Sanitary Science, Sociology and Economics are inseparable. We should not repeat the mistake of the beautiful but ignorant Marie Antoinette. When the hungry mob was shouting outside the palace window, she asked the cause of the commotion and was told that the people were hungry and wanted bread. "If they haven't bread, why don't they eat cake?" was her näive comment. I have often wondered how much good it was thought could be accomplished by urging poverty-stricken, penniless people of the slums and lung blocks to keep clean, eat plenty of nourishing food and sleep with the windows open in order to overcome tuberculosis when the total assets of the family couldn't purchase a cake of soap, when a fresh egg was beyond the means of the well-to-do, and when perchance there was no window in the luxurious one-room apartment. We should be careful about indulging in this type of humor—this is wit, bitter irony. It is with the science of economics that such conditions must be met. And we must not deceive ourselves with the belief that the rural communities have no problems of bodily cleanliness, diet or housing that can be remedied only by altered economic conditions.

The subject of rural sanitation cannot be discussed intelligently and comprehensively without taking into full consideration the domesticated animals. The ability of the farmer to heed the teachings of the sanitarian depends in great measure on the size of his bank balance although his mental attitude toward the whole matter is a big factor. The farmer's bank balance is frequently seriously affected by diseases of his livestock; for example, glanders may ruin a good pair of horses, tuberculosis may destroy a number of valuable dairy cows, infectious abortion may interfere with the natural increase of his herd by producing sterility in addition to causing abortions, or hog cholera may wipe out a fine drove of hogs. These are tragic events in the life of a farmer and result not only in a direct and tangible immediate loss, but produce a depressing and demoralizing effect on the industry in the neighborhood or in the country at large. It is not such diseases as foot and mouth that wrong the American farmer any more than it is the omnipresent, devastating plagues that I have mentioned that cause the losses, just as it is tuberculosis, typhoid and the like that cause the steady toll of death and disease in our fellowmen. From now on there will be spent millions in this country for the extension of information on matters of agriculture and domestic science to the rural population. One of the most influential publications making an appeal to women is insistent on the point of women getting a full share of this money for their particular sphere of activities. We frequently hear it said that one can get from the federal and state governments most accurate information on the subject of rearing and caring for hogs in health and in disease, but there is no governmental department to give advice in the matter of rearing children or the prevention and cure of human diseases. In other words, there are "millions for the pig but not one cent for the baby." Surely this makes a strong appeal and it has a grain of truth in it, but it does not represent the real situation. Personally I wish to do all possible to promote the welfare of the child and the adult especially through governmental aid and advice. I would much prefer to have my tax money disbursed through a national or state department of health than through departments of the navy or army, but I must protest that the work of our federal department of agriculture and of our state agricultural colleges and experiment stations in the suppression of animal plagues is done in large measure in behalf of the welfare of the owner of the livestock and of his dependents. Who can deny that the saving of the hogs from cholera may mean the very food and clothing, warmth and shelter to say nothing of education and culture for the child? Next to the will to do and the knowledge of how to do comes the wherewithal to do with. We are afraid that many of our rural dwellers have neither the will to

do the hygienic thing nor the knowledge of how to do it, but even with the will and the knowledge there is no accomplishing the sanitary ideal without the funds. Hence we find the problem of livestock sanitation inseparably bound up with the greater problem of human welfare.

A more direct influence of animal disease upon strictly human health is seen in those diseases readily intercommunicable between the lower animals and man. Foot and mouth disease, rabies or hydrophobia, glanders, and tuberculosis are notable examples. The relation of certain other diseases, such as infectious abortion in cattle is in doubt, but the very doubts urge us to make every effort to eradicate even the remotest possibility of danger. The American people owe it to the world to remove every cause of lowered efficiency in the food producing business of the country. Infectious diseases stand as probably the greatest direct and indirect burden borne by the animal industry of the country. Most of these diseases are eradicable. Pressure is usually exerted on the farmer by the producer to remove any possible source of danger to man from the meat food and dairy products offered for sale. I would appeal to the farmer's pride to urge him to wipe out any blot on the escutcheon of agriculture. We hear a great deal about the 54 per cent of producers and the 46 per cent of consumers and the necessity for protecting the latter. Has it not occurred to anyone that regardless of the high or low percentage of producers and their responsibilities in the matter of providing a sufficient and a safe food supply the percentage of consumers is a constant maximum—100 per cent. Doesn't the farmer consume his own product, and isn't he or shouldn't he be as interested in the food of his own family as is the city man?

In the relations of the farmer-producer to the city-consumer we find some time-honored agricultural and household customs entering as disturbing factors. I am afraid that many rural sociologists are teaching a discouraging doctrine to the effect that rural life must be and essentially is quite markedly different from urban life socially and industrially. I have even heard that it is quite essential that we develop a distinctive social class spirit in rural communities and that industrially agriculture is not amenable to the laws that govern other industries. The rural custom that I am thinking of is that one of hopelessly mixing the business of the farm with the domestic life of the family. Time will not permit of a discussion of the subject of the ultimate effect on happiness of conducting the manufacturing industries of the world in kitchen, living room or in the only room of the home or in a well organized, attractive and sanitary factory designed for a specific purpose. Shall the farmer have no real home life with his family and their pleasures to cheer him after his daily task or must the farm house be a factory for

the manufacture of butter, packing of eggs, curing of meat, sorting of apples and potatoes and for innumerable other of the little farm operations that from time out of memory have made domestic life on the farm so distinctive? Under these circumstances is there not sufficient explanation for the reluctance of the city woman to become a farmer's wife or for the farmer's daughter's willingness to leave the farm? Would it be unjust to accuse the farmer of sweatshop methods? Are there no dangers attending the food-preparing process in the ordinary farm household? Personally I am not so much afraid of these dangers, real or imaginary. I am opposed to sweatshop methods. I would divorce the domestic life of the farm from the industry of agriculture to the advantage of each. I am confident that this would react favorably on the quality of farm work and on the attractiveness and healthfulness of the farm home and would benefit mutually the farmer as a producer and the city man as a consumer. The farmer need not ape the foolish industrial or social customs of the urbanites, but why should he not avail himself of the good that is in city customs? Keeping the boys and girls on the farm and attracting desirable citizens as rural dwellers from all walks of life is simply a matter of bidding for the candidate and the inducements land the man.

Sanitary science demands perfection in health of the living organism and idealism in his environment. The practical attainment of the sanitary ideal in this country is possible only by three points of attack, viz: (1) Personal hygiene, (2) semi-public measures, (3) public measures. One might think that the whole solution rests with personal hygiene. If each individual body is hygienically sound then the body politic or the nation is sound. Too much emphasis cannot be placed on personal hygiene. The teaching of the care of the body and right living in the public schools, Sunday schools, at home and at all places, in season and out of season and at all times is necessary. We need gymnasiums and play grounds just as much as we need libraries and laboratories. We need better trained teachers and parents to teach hygiene and especially is this true in rural communities. All phases of hygiene should be taught. The conspicuous omission of one important branch such as sex hygiene should not be permitted nor should the spot light of overemphasis be thrown on any phase of hygiene. All diseases and conditions that affect the body detrimentally must be fought regardless of the route by which they enter or the manner in which they affect the body. It is folly to try to make oneself believe that there is no need of teaching personal hygiene in the country. It must be well known that all sorts of bodily defects and deformities as well as infections due to moral lapses or to unhygienic practices prevail in isolated communities as well as in cities.

A chain is no stronger than its weakest link and the hygiene of the community is weakened by one imperfect individual. Still we will not attain the ideal through personal hygiene alone. Public hygiene has to do with those matters that are beyond the control of the individual and must be attended to by the community whether local, state or federal. Hence the interference of government in matters of sanitation. The easy-going American government is quite in contrast with German precision and efficiency in this connection and spends little of either thought or money in the enforcement of sanitary regulations and promotion of hygiene in a broad and comprehensive way. We depend largely upon semi-public measures to afford immediate, tangible assistance and to arouse and direct public opinion on the one and to force governmental action or to act as a substitute for it on the other. In this connection witness the great and richly endowed research laboratories, the enormous sums for eradication of some specific disease as hook worm disease, the activities of life insurance companies and newspaper and magazine propagandas.

Society has learned that by concerted effort the interests of each and all are conserved. United social effort gives us clean streets, lighting systems, central heating plants, water and sewage systems, clean or safe milk supply, safe and sanitary public buildings and numerous other hygienic blessings common to the better class of American cities. But in what instance does the rural dweller profit by such devices? In the first place is there any organized social life in rural communities? There are the country school, the country church and the grange hall, but how many are well built, properly ventilated, comfortably heated, adequately lighted, thoroughly clean and attractive and supplied with flowing water of unquestioned purity, and with a sanitary sewage disposal system? I haven't seen one as yet. Are the farmers too poor to provide themselves with ideal meeting places? Or are we asking more than sanitation demands? The meeting places in the city meet with the plans and specifications, at least, many of them do, and if it is just a whim of the city folks and not a sanitary requirement then the farmer must remember that he is in competition with the city, which is bidding for his sons and daughters and they will select the place that makes the stronger appeal. If the business of farming is not sufficiently remunerative to permit the farmers to house their social organizations properly then there must be an economic readjustment or the business of farming will not make a strong bid for the most intelligent young men and women. I think the trouble is not due to lack of funds but to absence of will to do and in many instances knowledge of how to do.

How about the individual farmer in his home life? How few instances there are of co-operation or community effort in the way of supplying the farm house and buildings with light, water, sewage disposal system, heat or any sanitary necessities or modern conveniences! We hear of instances of the use of a creamery plant as a co-operative laundry, occasionally the farm house is supplied with water, gas or electric light when favorably located, but of few instances of real co-operative effort. And yet the farmer can have most of the conveniences of modern city life without prohibitive expense. The farm house must be well built with a view to lightening the burden of the housewife and to conserving the health of the family, there must be a good heating and lighting system, pure running water, safe sewage disposal, a pleasant outlook, and a place outside the home for industrial enterprises. There must be good roads and means of using them. There must be well constructed barns and stock shelters designed to safely and economically supply the needs of the farm crops and animals. The food produced on the farm must be as far above criticism as is that inspected by the city inspector. If the farmer cannot produce safe and acceptable food at current prices then there must be a readjustment. Under no circumstances should the American farmer, the representative of the most reliable and typically American ideals today, permit himself to be humiliated by investigations which presuppose that his product is of questionable quality. The farmer must produce pure milk, clean meat, fresh eggs and perfect fruit and vegetables and collect—I said collect, not accept what is offered—all that is necessary to recompense him for his trouble. No self-respecting community of farmers should wait to be coerced into improving their milk supply. It is their business to produce safe and clean milk and to get paid for their effort. It is their business to produce meat that will pass the most scrutinizing inspection and to demand this inspection just as a reliable manufacturer demands that the machines that bear his trade-mark be as specified. I know of no way that an approach can be made to this condition except by enlightened self-interest.

The relation of governmental health agencies to the farmer must become more intimate. In the control of the recent outbreak of foot and mouth disease we have experienced a most remarkable example of governmental interferences in the farmer's business. The U. S. Bureau of Animal Industry and the State Livestock Sanitary Commission of Michigan co-operating have destroyed private property and paid for the same with the result that a foreign livestock plague has been eradicated from the state. This result could have been accomplished only as a result of the hearty and intelligent co-operation of the Michigan farmers and local officers. Never has there been shown a better, intelligent—not

abjectly submissive—spirit of co-operation in a piece of sanitary work the full significance of which could not have been appreciated by the farmers. In the light of this recent experience in Michigan I am encouraged to hope that the Michigan farmer is ready to co-operate in every reasonable movement to better the sanitary condition of Michigan farmers.

Comparisons are said to be odious; they are also necessary and instructive. In closing I may be permitted to call your attention to the comparative condition of city and country from the health standpoint as presented by a great medical scientist and by a distinguished social scientist. Vaughan says: "It is significant that for this considerable portion of the country (the original registration area), the death rate of the rural districts shows but little, if any, decrease in the years and periods compared. Practically the entire reduction of the death rate in this group is due to lower urban mortality." An effort has been made to secure legislation along health lines that would guarantee the rural communities advantages equal to those enjoyed by citizens of the large cities. "The children of the poorest, most ignorant immigrant in Detroit go to sanitary school houses; they are inspected daily by medical men; any deviation from health is detected and attended to. The infected individual receives attention while it is still time to be of service, and the spread of disease is prevented. These same children are inspected by the dentist, and when there are oral defects and the parents are not able to pay for proper attention, the city pays for it. When a child of one of these poor, ignorant immigrants is taken with scarlet fever, it is carried to the City Hospital where it has the very best of care and treatment without expense to the parents."

In discussing the reasons underlying the movement of farmers to the city, Carver says: "The country is still somewhat more healthful than the city, though there are some perverted statistics which aim to show the contrary. But the undoubted fact is that the cities are improving very rapidly in sanitation, and the time is not far distant, unless the country districts arouse themselves, when the cities will be more healthful than the country."

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SANITARY AND MEDICAL SCIENCE.

# ANAPHYLOTOXIN AND AMINO ACIDS.

BY WILLIAM MC K. GERMAN.

Shortly after the phenomenon of anaphylaxis was observed it was noticed that both normal and sensitised serum, ordinarily harmless to the same and other species upon injection, became highly toxic when subjected to proper treatment, and produced symptoms identical with those of anaphylaxis. The name anaphylotoxin has consequently arisen and the phenomenon is thought by most workers to be closely related to that which occurs *in vivo* in a sensitised animal.

Thus Friedmann has obtained a toxic principle by treating sensitised cells with normal serum, which killed guinea pigs with typical symptoms. Friedberger substantiated Friedmann's work by obtaining a similar poison from sensitised bacteria and normal serum. To this he gave the name anaphylotoxin. He believed of course that the poison arose not from the serum but from the antigen—in this case from the bacteria. This is logical and perfectly easy to believe.

Later it was discovered that normal serum treated with such substances as kaolin, talc and agar produced a similar poison. In that case could that poison arise from the antigen? Or could it arise from the serum? Friedberger believed that in the case of agar the poison came from the small amount of nitrogen contained in the agar. Agar and other similar colloids are normally harmless but when 5cc of normal serum are treated with 1 cc of a 0.5% solution of agar which has been shaken to form a viscuous mass and exposed to 38 degrees for two hours it gives rise to a potent anaphylotoxin. Bordet and Zunz by freeing agar of all but a trace of its nitrogen obtained a product which they called pararabine and was identical with agar in all its physical characteristics. This, too, gave rise to the same anaphylotoxin quantitatively while the nitrogenous extracted residue proved to be quite harmless. Therefore Zunz would have us conclude that the poison has for its source the serum of the animal body and not the agar or the antigen in general.

Bordet and Zunz further showed that with the production of anaphylotoxin there was an increase in amino acids, indicating cleavage. Their method was briefly as follows: The serum was incubated at 38 degrees with one-fifth its volume of 0.5% pararabine, centrifuged and the proteins removed by precipitation with ten volumes 95% alcohol. The precipitate

was then filtered off and the remaining filtrate containing the amino acids was freed from its alcohol by evaporation and subjected to the Van Slyke method for the determination of amino acids. The results showed an increase in amino nitrogen over a control which was treated with the same volume of .85% salt solution.

Since the majority of theories of anaphylaxis involve proteolysis, it has occurred to us, too, to investigate the anaphylotoxin production from the same standpoint. Is proteolysis the cause, is it concomitant with or is it related in any way to the production of anaphylotoxin? We have made use of the Van Slyke method for the determination of amino acids of proteolysis and have used agar as the anaphylotoxin inducing agent. Our technique otherwise was the same as that of Bordet and Zunz which I have explained.

### RAT SERUM ANAPHYLOTOXIN.

By the use of rat serum treated with agar we have been able to produce anaphylotoxin in five minutes. Bordet and Zunz by using guinea pig serum obtained their toxin after two hours' incubation. By production of the maximum toxicity in the shortest period of time we sought to eliminate the chances for the hydrolysis of the serum proteins by the action of enzymes or any other cause. We were thus able to show repeatedly that rapid toxification of rat serum with agar was accompanied by a decrease in amino acids over controls of untreated serum incubated for the same length of time, rather than an increase as one might expect.

The use of guinea pig serum gave us the same results. We are able to produce a potent toxin from normal guinea pig serum with 15 minutes' incubation. In every case in many series of experiments a similar decrease in amino acids was found to accompany toxification.

Thinking that if the time of incubation were increased we might find an increase in the amino acids of hydrolysis we incubated both rat and guinea pig serum with agar for varying lengths of time from three to 24 hours and observed that after the preliminary drop there was a gradual rise in amino acids but at no time even after 24 hours' incubation did the quantity of amino acids reach that of the control untreated serum incubated for the same length of time. The control, too, showed the same gradual increase in amino acids pointing to the possibility of serum autolysis with incubation. Normal guinea pig serum treated with agar which is removed at once without incubation shows the same fairly marked decrease. We are at a loss to explain this phenomenon and for the present attribute it to adsorption by agar surface. An attempt has been made to recover the amino acids thus adsorbed but without success.

### DISTILLED WATER ANAPHYLOTOXIN.

We have been able to produce anaphylotoxin by the dilution of sera with distilled water. Thus normal and sensitised rat serum can be made toxic. Normal rat serum diluted one to six produces a relatively powerful anaphylotoxin when incubated 30 minutes at 38 degrees C. Sensitised rat serum, i. e., serum sensitised to egg white when similarly treated, becomes toxic with five minutes' incubation. Here if any place one might expect to find proteolysis. The results that have been obtained shows a slight increase in the case of sensitised serum but the usual drop when normal rat serum was made anaphylotoxic by dilution with distilled water.

### INULIN.

Nathan has shown that the polysaccharide, inulin, produces anaphylotoxin from normal guinea pig serum and that its ability to do so depends upon its physical state. An inulin suspension produces the toxicity readily while a solution of the same substance fails to initiate such toxicity. A 5% suspension in .85% salt solution was used. The experiments were carried out in the usual manner on normal guinea pig serum using as a control untreated serum.

After 30 minutes' incubation at 38 degrees C. it was noted that the toxicity was marked but did not at that time reach its maximum. Coincident with it was a slight increase in amino acids. At 90 minutes the toxicity had reached its maximum but the amino-acid content actually fell, in as great proportion as it had previously increased. So, while there is a primary increase in amino nitrogen it fails entirely to keep pace with the intensity of toxicity.

Similar experiments carried out on rat serum substantiate this result. In every case no increase has been observed and is markedly less than the control of normal untreated serum.

Sensitive serum can be made anaphylotoxic by incubation of that serum with its corresponding antigen. Using egg white as antigen one might expect here if ever with an antigen capable of hydrolysis an increase in amino acids if proteolysis were involved. Rabbit serum sensitised against egg white was used and incubated with its antigen for various lengths of time. Repeated attempts failed to demonstrate any increase in amino acids accompanying toxification. The same was true when guinea pig serum sensitised against egg white was used. Careful search has failed to disclose a shred of evidence that would connect the digestion serum proteins with the formation of anaphylotoxin. In two or three instances slight increases in amino nitrogen has been detected at times when the serum has been toxic. But in each of these instances

the use of another inducing agent on the same serum has given rise to toxicity without an increase in amino nitrogen. Proteolysis proceeds not by the resolution of a protein molecule into halves, quarters, eighths and so on, but by the gradual lopping off of simpler constituents, amino acids or amino complexes, until the molecule is totally disrupted and this is especially true in the case of the action of ferments. Even if the former were true we should have double, quadruple, eight times, etc., the amount of amino nitrogen liberated. By the Van Slyke's method, the most accurate process in use, differences in hydrolysis in terms of a few hundredths of milligrams nitrogen can be detected. We can state therefore that no proteolysis in any way accompanies the production of anaphylotoxin in serum.

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# CHEESE POISONING.

BY WILLIAM LEVIN.

Cheese poisoning was very common in Michigan in the eighties of the last century, about 300 to 400 cases being reported to the State Board of Health in 1883-1884. Vaughan,[1] in 1884, working with samples of the poisonous cheese, obtained a ptomaine which he called tyrotoxicon, and which he considered the active poisoning agent. His work was corroborated by several investigators.[2, 3, 4] Lepierre,[5] in 1894, extracted a base having the formula $C_{16}H_{24}N_2O_4$ from poisonous cheese. Dokkum,[6] in 1895, considered tyroxin, a base which he had obtained from poisonous cheese, the poisoning agent. All these investigators were of the opinion that cheese poisoning was an intoxication. With the bacteriological methods of analysis, however, it was soon shown that the poisoning was caused by certain organisms, usually of the B. Coli group, and was to be considered, therefore, not an intoxication, but an infection.[7, 8, 9, 10]

On June 21, 1916, the Hygienic Laboratory received a piece of American cheese, of about 100 grammes, from Dr. W. S. Tomkinson, of Kalamazoo, Mich. The sample was part of a cheese which had caused marked gastro-intestinal disturbances to a family of six, including four children, in that city. On bacterial analysis an organism was isolated which proved pathogenic to mice. After passage through several mice the organism had increased in virulence to kill rats; and after passage through these, to kill guinea pigs. The organism was then passed through about fifty guinea pigs, isolated from the heart blood of the last animal, and obtained in pure culture. The organism isolated from the cheese is a facultative anaerobe, having the size of B. Colon. Its motility depends upon the age and the kind of media in which it is grown—ranging from very marked to practically no motility. It is Gram-negative, not acid-fast, and forms no spores. It ferments pentoses, hexoses, di- and tri-saccharides, and dextrin. It reduces nitrates and forms indol.

Agglutination tests showed that the bacillus is related to the colon group. Immune sera of several organisms agglutinated the cheese poisoning bacillus in the following dilutions:

Immune colon serum, highest dilution, 1-800.
Immune paratyphoid A serum, highest dilution, 1-10.
Immune paratyphoid B serum, highest dilution, 1-50.
Immune enteritidis serum, highest dilution, 1-50.

The immune serum of the cheese poisoning bacillus agglutinated the above organisms in the following dilutions:

| | |
|---|---|
| B. Colon | 1-100 |
| B. Paratyphoid A | 1-10 |
| B. Paratyphoid B | 1-10 |
| B. Enteritidis | 1-10 |
| Cheese poisoning bacillus | 1-2000 |

The bacillus was found to be pathogenic not only to mice, rats, and guinea pigs, but also to rabbits, cats and dogs. In cats, interperitoneal injections of the organism causes retching, vomiting, and purging, and also a high fever. When injected with peritoneal exudates from animals, as guinea pigs, killed by the bacillus, the cats die within 12 to 24 hours. Feeding of the poisonous cheese or of food, as milk or meat, saturated with a culture of the organism, produces no effects.

The organism does not form tyrotoxicon. It does elaborate a soluble thermo-stabile poison in sugar media, preferably a 0.5% lactose broth, neutral to phenolphthalein; 0.25cc of the sterile filtrate of such a culture kills a 100 gram guinea pig within five hours. When injected into cats the filtrate causes the same symptoms as the virulent organism. Rabbits give a marked febrile reaction.

Milk cultures of the organism, when incubated at 37° C for thirty days, will become curdled. If now the whey from such a culture be separated from the curd and sterilized by filtration through a Berkefeld candle, and then extracted with alkaline ether, it will be found that this extract may possess some toxic action on guinea pigs. If guinea pigs be injected at intervals of five to seven days with increasing doses of this alkaline ether extract they will show a marked protection against, and at times complete immunity to, virulent cultures of the organism.

Guinea pigs can also be immunized to the virulent organism by vaccine and immune serum injections. Immunity to the soluble poison is more difficult to obtain.

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# ECONOMICS.

# GOVERNMENT AND ECONOMIC EFFICIENCY.

BY E. H. RYDER.

Problems of economic efficiency are naturally considered from the standpoint of so-called economic laws. These laws have been formulated from reliable data carefully gathered by observation of certain industrial conditions. If these industrial conditions continued unchanged or no new factors were introduced, these generalizations would remain acceptable, and might be relied upon as a means of maintaining just and equitable relations both for the producer and consumer of economic goods.

The industrial conditions which underlie the formulation of these economic laws are the conditions of a relatively simple and natural industrial life where each individual is largely self-sustaining or may be so, where the economic goods demanded are few in number or easily capable of substitution; furthermore, in an industrial period when the individual could seek relief from objectionable conditions by turning to the land from which subsistence could be derived without the possession of large capital.

But society has not remained thus simple in organization in very recent years. New factors of great consequence have entered into the determination of economic conditions whose influence can not be ignored or indifferently set aside. Production, instead of being widely distributed as in the early stage, is concentrated in many lines in the hands of the few; instead of a large number of producers utilizing relatively small quantities of capital, the business is centralized in the hands of the few with enormous aggregations of productive capital. Coincident with this concentration of productive factors has developed a highly specialized consumer who, absorbed in some phase of production, has a wide range of wants but possesses little knowledge of actual productive processes. The economic goods used are produced under conditions totally beyond his range of knowledge. This transformation coincides with the evolution of the industrial corporation which institution has resulted in a beneficent efficiency. However, these blessings of corporate scale production have been accompanied by portentous evils which have brought burdens to society in the way of poverty, disease, imbecility, etc., all of which have become by-products of modern industrial conditions. Along with these objectionable conditions comes another evil of special sig-

nificance, viz., that of control of product. This has been accomplished in various ways as we all know. It may take the form of possessing the raw material from which an important product is made, or may limit total production as the means to the end. Today this evil expresses itself in the disturbance in distribution. In insidious ways the supply of products is manipulated. Cold storage, an agency for extending the utility of a product, becomes the agency for control of supply and price of necessary food products. In a variety of ways the retailer finds the prices which he charges are not competitive prices, but are predetermined by some agency whose command he can not disobey with impunity. No multiplication of retailers in accordance with the economic law effects relief, oftentimes because such retailers cannot obtain supplies of the products.

The appearance of this control asserts itself at a critical stage in the economic and social progress of the people. Access to the land is about to terminate, since free lands no longer exist. The proportion of raw material producers is constantly lessening. A dependent portion of population relying upon a constant supply of food and other products has been constantly growing. These individuals, not only have no opportunity to reach the land but have no acquaintance with methods of production of food products; furthermore they do not desire such activities, have no habits of husbanding their resources effectively but live from pillar to post, thus becoming easy prey for the schemes of organized controllers of wealth. They look to an economic system of distribution which will bring to their stomachs the necessary food and to their backs the essential clothing at prices which are the cost of production and within the reach of their incomes. It is at this point that our economic laws are breaking down at this moment. Today society is suffering from this purposeful failure in distribution with the result that society is paying excessive prices for many of the necessities of life. The truth of this assertion is verified by the experiences of the nations at war where dire necessity has forced the cost of living down to rock bottom prices with the result that living is much cheaper there than here. We do not contend that similar prices should exist here or are desirable or possible under normal conditions, but we do believe that it will concentrate attention upon individual expenditures for the necessaries of life in this country and raise the query as to unwarranted profits upon articles in common use. This conclusion is inescapable.

It is merely to call attention to commonly known facts to say that government has already intervened in behalf of the suffering consumers and producers. No less conspicuous than the Industrial Revolution of the past century is the political revolution of that period. Our fore-

fathers in shaping their policies of government pledged themselves to the idea that government should not interfere with private industry. In other words, individualism was accepted without qualification. Furthermore, government was to be feared and its possible exercise of unwarranted power or authority must be forestalled by shackling its powers through the guarantee of personal liberty for individuals in the way of constitutional provisions against the invasions of freedom of speech, property, the press, trial by jury, etc. This fear was largely imaginary, for experience has found little danger from such a source through the intervening century.

Experience has proved that in recent years danger to the individual is not from government but from his fellow citizens whose desire for control of industrial activities and the profits thereof, has transcended his respect for the welfare of his fellow-citizens, who find themselves compelled to invoke the interference of government with the nation's industries. Government, instead of actually being the thing to be feared, is the people's hope of salvation in the maintenance of a new liberty, the necessity for which was unthought of a century ago.

It is not my purpose to detail the experiences of the American people which have been the outcome of this change in the relation of government to industry. From the Granger legislation of the 70's has come the distinction between the public utility corporations and private corporations. It was no easy task or no small achievement for the public as well as the corporate holder to establish and accept the principle of control involved in public utility organization. The next step was an assertion of control over private corporations, in respect to monopoly. The prolonged campaign over this problem and the disputed results thereof are too fresh in our minds to necessitate any very specific statements other than that the people accept this interference of government as a justifiable function, necessary to the preservation of individual rights.

In this legislation our government has aided the consumer by attempting to preserve fair terms of service without the existence of competition in one case, thus setting aside the individualistic principles or by attempting to insure the continuance of competition in the other, thus preserving individualism. Aside from the public utility corporations, the government has relied upon the efficiency of competition as a means of fixing prices on the assumption that the removal of certain gross, objectionable, obstructive practices would clear the way for an efficient competition.

It seems apparent from experiences from year to year that this competitive condition is not restored and maintained, or if it exists it is in form only. As a result, the public is continuing to look to the govern-

ment for further relief, while government continues to rely on the efficiency of the competitive idea. Is it to become the function of government to take a closer relation to production and distribution as a means of protecting the public from the ravages of the private corporation? Additional aid has been sought through the force of publicity brought to bear upon objectionable conditions and finally by the Federal Trade Commission as an administrative agency.

There seems to be sufficient reason for contending that these means have not satisfactorily suppressed the evils from which we suffer. In fact it seems apparent that these practices, instead of being eliminated, are characterized by more objectionable tendencies than at any previous time. Profiting by the past efforts the control of products is achieved in more elusive ways, and a seeming scantier regard for public opinion and natural conditions of human interchange of commodities and services.

This statement is made in full realization that the present is an abnormal period, when excessive prices may be more easily exacted. No less obvious also is the fact that under production is accountable for high prices in some instances today as for example, potatoes and beans in Michigan.

However, eliminating from our consideration these two facts as explanatory in some measure of the present high prices and scarcity of products there remains indisputable evidence of high handed practices in the involuntary confession of the paper trust and the unsavory revelations of the governmental investigation of the coal situation. The unblushing effrontery with which men have held up the public in both of these instances, and extorted from a helpless public exorbitant prices, in the one case driving individuals from the pursuit of business, in the other causing immeasurable suffering (in the case of the coal combine proposing to continue extortionate prices through the coming year), is unmistakable evidence of the above contention that the practice of control of industrial product is even more serious than heretofore. That the control of wealth is a very present and serious feature in our civilization.

Such facts serve to make the ordinary citizen wonder to what extent similar conditions are accountable for many other high priced products and to what extent the business world is dominated by illegal combines. Certain it is that such facts not only shake one's faith in human nature, but also in the efficiency of all those working principles of business which one has relied upon in the past to preserve justice among men.

Certain it is that some adequate solution of this grave problem must be found and applied, or emboldened by these uncurbed successes, future corporations in increasing numbers will extort from an unprotected con-

sumer unlimited sums of money thereby enhancing great fortunes and driving an enraged public into unknown efforts at self-defense.

In reply to the question what can be done, one can find but one answer, and that is in bestowing upon an authorized commission the power to fix the maximum prices of commodities which are likely to be subject to manipulation. This would seem to be the only way to safeguard the public from evils which are being perpetrated before remedial steps can be taken under present conditions. The public has with commendable patience accepted through a goodly period the policy of competitive forces as a means of protection. Courage was stimulated by the creation of a Federal Trade Commission whose function should be to call upon the carpet the venturesome manipulator, but when two such bold cases of restraint confront us as the recent ones, we are constrained to meditate upon the outcome of this competitive policy, and to wonder if it has not already been the means of intrenching enemies of the welfare of an unsuspecting public. Hazardous as price fixing may seem to be and impracticable as an industrial policy, what else can avail?

Not only, says the defender of the interests, is price fixing as a means of protection an impracticable method of meeting this evil, but it is at variance with our constitution in respect to property rights. This, of course, is the reliance of the corporation against any such heroic remedy as that of fixing prices.

There can be little doubt that the public and the courts are disposed to set aside this protective agency behind which the property owner has taken refuge time without number and continued to perpetrate unwarranted practices.

For the present it may suffice if the court shall place many businesses in the class of public utilities where they would be subject to regulation through being of public interest. Doubtless the view of our courts as to the meaning of public business is undergoing change. In a recent case*—German Alliance Insurance Co. vs. Ike Lewis,—the court was unable to give any fixed definite mark of this change from private to public interest. Furthermore, it refused to classify as public businesses only those which had a monopoly or those which had received from the public some special privilege. Justice McKenna, who delivered this opinion, took the broad ground that without either of these distinguishing marks a business might become of public interest through the simple fact of its necessary influence on great numbers of people.

A second evidence of the attitude of our courts which bears upon this problem is found in their exercise of the police power. It is well established that the state may through this power protect public health,

*233 U. S. 389, 1914, Young, The New American Government, p. 469.

safety and morals, and in so doing may even interfere with fundamental private rights, if necessary. The length to which the state may go is voiced by Justice Holmes† in Noble Bank vs. Haskell, as follows: "The police power extends to all great public needs. It may be put forth in aid of what is sanctioned by usage or held by the prevailing morality or strong and preponderant opinion to be greatly and immediately necessary to the public welfare."

The trend of the court is toward the recognition of the right of the government to assert its authority to a greater degree in the affairs of business. Prof. Freund‡ in his work on the police power has set forth the legal aspect as follows: "The justification for regulating charges in some particular business would usually be that it constituted a de jure or de facto monopoly or enjoys special privileges; but it may also be that the commodity selected is a necessary of life or that it is essential to the industrial welfare of the community."

It is significant that the courts in so many recent decisions have upheld principles of the above nature pointing toward judicial relief for these conditions.

Why should this policy be entered upon?

It is the only method whereby the public can be protected from excessive cost for necessities of life, short of public ownership of the means of production.

Again it will be a means of effecting a fairer distribution of the product according to the needs. Without such price regulation, the product will be disposed of at highest price regardless of relative regional needs.

Finally, it would place some limit upon the accumulation of excessive wealth. The elimination of competition creates perilous situations industrially in that it tempts men to seek undue profits. This tendency prevails in respect to a very large number of products today and is a condition fraught with far reaching economic and social possibilities which it would seem must be met by some effective measures.

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†U. S. 104, 1911, Young, p. 513.
‡Freund—The Police Power, p. 380.

# THE FUTURE OF THE COUNTRY CHURCH.

BY ROBERT PHILLIPS.

During the last few years, public attention has been attracted to a newly developed socio-religious subject of discussion, now known as "the problem of the country church." There had previously been little mention made of the country church as presenting a problem distinctly its own. It had always been identified with the church as a whole. And while many perplexing questions had frequently arisen regarding the place of the Christian church in society, there had been no differentiation made between the rural and urban branches of the institution.

Recently, however, there has appeared a wealth of literature, treating the distinctively rural side of church organization. The general impression seems to be that the country church of today is facing an alarming situation, a situation that bears no close anology to conditions within the cities. And suggestions for improvement apparently imply that its plight is the natural consequence of social changes peculiar to rural life. That it may be the consequence of a transformation of the whole social structure, involving equally the cities is not so clearly apprehended. Hence the widespread speculation as to the problems and future possibilities of the country church as distinguished from the city church.

It must be admitted that the institution is in some respects suffering seriously throughout rural United States. This is attested by the annual reports of most of the Protestant denominations for the last thirty years. Since the days of the circuit rider thousands of church edifices have been closed. Thousands of others are lingering on at the point of exhaustion, it being only a question of time before they, too, will be closed. The attendance has been dwindling away, until the congregations are now only a shadow of what they were in former years. The salaries paid to pastors show as a whole no increase, rather a decrease, especially in proportion to the higher cost of living. And contributions made to benevolences are smaller; for the majority of these organizations are finding it more than ever difficult to maintain the salaries of their pastors. Gill and Pinchot making, under the auspices of the Commission on Country Life, a survey of Windsor County, Vermont, and Tompkins County, New York, reported a slight increase in rural church membership, but a signal decrease in attendance. The situation in these counties

has changed during the last twenty years, from a preponderance of attendance over membership to that of membership over attendance. This may be ascribed chiefly to negligence in removing names from the rolls; but is also in great measure due to the fact that even actual members no longer faithfully attend the services.

I have visited a number of the rural and small town churches in the north central states; and almost without exception have found similar conditions prevailing. The congregations are reduced, and there is a noticeable indifference on the part of all except the few faithful old people who form the nucleus of whatever interest remains. These are the sole vestiges of a once dominant faith, that is gradually passing away. Upon questioning the older residents, I have been informed that a generation or more ago their churches were filled to overflowing at both preaching and Sunday school services. But somehow "people have fallen out of the habit of going to church," so the religious life of the country community is on the wane. There is, therefore, no room for disputing the fact that the rural church of today represents a serious problem. And unless an adequate solution is provided, it may soon cease to be a factor in rural life.

The situation in the country church, however, is not essentially different from that in the churches of our cities. The last few years have brought about almost as striking and significant developments in the latter. There is a steady falling off in attendance at both the Sunday and the mid-week services. Even the coming of a distinguished religious leader, once the occasion for a general turnout, now attracts no more than passing attention. There is undoubtedly no diminution in the number of names upon the rolls, nor in expenditure for usual purposes. But the growth in membership is not proportional to the growth of population; nor are the expenditures keeping pace with the rising cost of living. Moreover, the very fact that people, while contributing to the upkeep of the church, are absenting themselves from its meetings, is an ominous presage for the future. It is not human nature to long continue to support an institution which presents no compelling interest, and from which no direct personal benefits are derived. The city, therefore, is struggling with a religious depression that is fundamentally no different from that of the open country.

If the straightened circumstances of the country church are the more acute, as they undoubtedly are, the cause may be attributed to its representing the marginal members of the institution. Country church organizations may be said to be on or near the margin in that they are able only to meet the absolutely necessary running expenses, with possibly a small surplus for benevolences. The city church, on the other hand,

usually has a much larger constituency. It formerly raised a considerable surplus over the required expenditures; and has not as yet been reduced to the vicinity of the danger line. What, then, must be the inevitable result of failing support? It must affect the country churches first; and this accounts for the thousands of them that have dissolved during the last generation.

The decline of the country church being paralleled by that of the city church, we can scarcely speak of the former as presenting a distinct and separate problem. It is rather the rural phase of a problem that is threatening the existence of the institution taken in its broadest aspects. And the fortunes of the individual members will depend upon the wellbeing of the whole. All attempts, therefore, to diagnose the failure of the country church must begin with the institution as an organic whole.

What in general is the outlook for the future Christian church? May we prescribe it as a decadent social structure, that has served a period of usefulness, and is doomed to extinction? Is it in a temporary period of depression, from which it may be expected eventually to recover? The answer would appear to be that it is in a state of transition, undergoing a metamorphosis that will readapt it to its environment. The old passing structure, whether or not adequate to supply past needs, has become unsuited to modern conditions, and a readaptation is now demanded. The consequence must inevitably be a new organization, imbued with a new purpose.

The dominant feature of past ecclesiastical history has been the tendency to overemphasize a so-called dualism in man's nature. This has come largely from the theology of Paul, upon which the church has based too much of its doctrine. The Pauline theology is a form of dualism in its clear-cut separation of the spiritual man from the natural man. And from this the church has derived its conception of the spiritual life and the natural life as two distinct entities. Moreover, there was held to be an irreconcilable antagonism between "things carnal and things spiritual." To preserve the spiritual life undefiled it was necessary to keep it, as far as possible, from contact with a contaminating world. Thus the separation of the church from secular life.

This doctrine of "otherworldliness" is now doomed, if we may judge by present day criticism. The world is beginning to question the value, and even the existence, of a spiritual life separated from the natural order. The growing demand is for a theology that will unite the spiritual with the natural, the one being but a higher interpretation of the other. Religion, to be worthy of the name, should permeate the social order in which men move. Its object is not to introduce a new essence into man's

makeup, but to transform the old life; and to accomplish this purpose it must reach out into every field of human activity.

There is a common impression that religion, education, government, and other institutions are discrete social structures. Their functions are held to be unrelated, and their positions in society non-intersecting. Each should be circumscribed in the field of its operation in such a way that it will not infringe upon the domain of others. Thus, religion is the function of the church, education that of the schools, law that of the government. The church must not meddle with education, nor with law; nor may the others transgress their own proper spheres of influence. If this were a correct interpretation of the interrelation of institutions, it might be illustrated as follows, the large outer circle representing the field of society, the small inner circles prominent institutions:

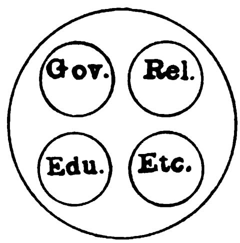


Figure 4. Diagram to illustrate conception that religion, education, government, etc., are discrete social structures.

But such an interpretation can scarcely do justice to the real and proper relations of institutions to one another and to society as a whole. It ignores the organic conception of society. There is indeed a peculiar function belonging to each institution, but taken in their ensemble they should function in unison. Consequently, no one of them is to be confined to any specialized part of the field of social life; but rather each should permeate the whole field. In the figure above, therefore, each circle designating an institution should be enlarged until its periphery coincides with that of the outer circle as follows:


Figure 5. Diagram to illustrate proper conception of the relations of religion, education, government, etc., in the field of social life.

It is difficult to think of society apart from its fundamental institutions. Religion, education, government, recreational and fraternal organizations, alike, have all exerted a pervasive influence upon the sum total of social life. And, although their functions may be differentiated, their fields are the same, the whole of society, by reason of which they cannot logically be assigned to separate domains.

Heretofore it has been erroneously conceived that religion, or the spiritual life, should, as much as possible, be separated from the natural order. Inasmuch as the church was the guardian of spiritual life, she must be isolated from all institutions dealing with material things. But the attitude of religious thinkers toward this question is today undergoing a radical change. The purpose of the church, as now understood, is not merely to create in the individual a new and separate life, called the spiritual, but to transform and uplift the natural life; not merely to prepare for a future world, but to spiritualize the present world. And its purpose will not be accomplished until it has leavened every sphere of human activity with spiritual ideals. Why, then, isolate the church from secular life? Its aim should be a thorough, aggressive invasion and conquest.

Needless to say, when once the church has awakened to its mission we may look for sweeping changes. There is going to be reorganization, a new program, a new attack. We are concerned here with chiefly the rural phase of the situation. For if there is to be a readaptation to meet modern requirements, there must necessarily be a varied program, adaptable to dissimilar types of society. And what will be the adjustment made to country life? Conditions among the farming class of people present some characteristics that are not to be found elsewhere. To these there must be a widespread attempt at accommodation; and although there is but one general church problem, the country church must attack that problem in its own peculiar way.

It is to these possible plans that I propose to devote the remainder of this discussion. No one will venture to prophesy in advance precisely what they will be. But there have been launched certain progressive movements that give a strong foreshadowing of what is to come. And to a review of these I am going to add a few suggestions for improvement. For this purpose I will divide the subject into its three main aspects, as follows: (1) organization; (2) pastoral requirements, and (3) equipment and program.

There can be no question that the present unsatisfactory organization of the church has been largely responsible for its failure to accomplish its mission. It has been to a deplorable extent subject to a form of faction known as denominationalism. Factions have been the bane of

every social institution, and the church has been a prey to its inroads more than has any other institution, with the possible exception of government. There may be some justification for denominationalism within the larger cities, though even here we may expect a gradual union of those sects which are similar in creed and ceremony, and federation of those which are too dissimilar to admit of consolidation. In the country, however, there is no valid excuse for denominationalism that is not heavily outweighed by the case against it. And the various sects are at present awakening to the fact that a country community can reasonably support but one church. There is a growing undercurrent of disapproval of the practice of trying to establish and support in a single neighborhood a number of sickly organizations, no one of which can pay its pastor a sufficient salary, nor actively engage in community work. It is encouraging, therefore, to note the tendency today toward co-operation, especially among the evangelical churches, for the purpose of pooling the territory and dividing it among them. If this movement goes as far as it should, there will eventually be a widespread process of elimination, only those churches remaining which offer the possibility of efficient service. In the country, more than one church to the community is a waste of time, energy and expense. To eliminate many of them would ultimately result in both economy and efficiency, higher salaries, more able pastors, a unified program. The future of the country church depends upon this reform.

In addition to the drawbacks of sectarianism, the church must meet the problem of establishing a centralized control and direction. Some of the denominations already possess a more or less flimsy structure of centralized supervision. But there is an urgent need of some permanent central committee, or council, within each sect, the business of which shall be to study social and religious problems, with the best methods of attack; and to outline programs of work, giving information and expert advice upon every subject. They should make a study of different types of communities, with a view to determining their peculiar needs and the best methods of proceeding to meet them. And it should be their duty to instruct and advise the pastors in their work.

One subject of each system would be to remove the center of initiative from the official board of the church to an experienced central body of experts. The typical church official board is as incompetent as the average rural school board. Its members are ignorant of the latest thought and of improved methods; and they are, as a rule, not sufficiently energetic and enterprising to undertake a progressive propaganda. Whatever individual church initiative there is, under present conditions, it is stimulated by the most aggressive of the pastors. And their work

is usually dropped upon their removal, generally because of incapacity in their successors. With the system here proposed the initiative and enterprise is embodied in a continuous council, chosen for experience and capacity, having power to initiate activities, to supervise them, and to insure their continuity.

Such a body could, obviously, administer only to a limited area. So it would be necessary to provide some superstructure to form a connection between areas. Above all it is highly desirable that there be a national organization, such as the Federal Council of the Churches of Christ, uniting all denominations, in a more or less compact whole. This would bring about a mutual understanding, which would go far toward promoting a singleness of purpose, unity of methods, and broad co-operation. The evidences all point toward a coming centralization of direction, and a closer bond of sympathy and association among religious sects.

If the official board is shorn of its former powers, what position should it occupy? Its best services could undoubtedly be performed as a pastor's cabinet. It would consist of leaders in the various fields of church activity, the Sunday school superintendent; presidents of the brotherhood, the Y. M. C. A. and Y. W. C. A., the W. C. T. U., and young people's organizations; the deaconesses, and others. Preferably it should be constituted by one member being selected from each field. The functions of the members would be to meet with, advise, and be responsible to, the pastor.

From the district council, or committee, down, the organization of a highly centralized and efficient church would be as in the following figure:

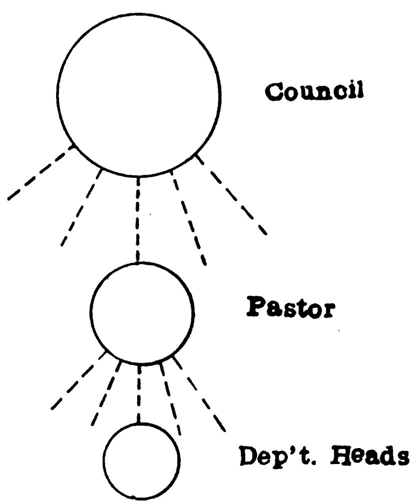


Figure 6. Diagram to illustrate suggested church organization.

Here direction of church work flows from the district council to the pastor and thence to the heads of the departments of work, not from the pastor nor official board as originators. This is similar to the organization of our public school system. The strength of such a system becomes apparent when we consider the present position and qualifications of the average pastor. The average pastor is not qualified to plan, organize, and conduct so far reaching a program as will be expected of the future church. He must be directed and assisted by a superior authority. Especially is this true of the country pastor. In the past we have been sending to our rural churches either old men, incapacitated for active service, or young men entering upon their first pastoral experience. The meager salaries paid have made it impossible to send more competent men. When the surplus number of country churches becomes eliminated, however, and when a new, living program is instituted, there is going to be a steady increase of salaries. This means that more capable young men are going to be drawn to the ministry. And since the number of appointments will be reduced, we may feel confident of a much superior pastorate. Nevertheless, well qualified as the coming pastor may be, he will not by himself be able to study out, and satisfactorily solve, every need of his parish. He must be more or less dependent upon authority above him to guide and instruct him.

If recent alterations in the curricula of theological seminaries may be taken as a criterion, there is due a much improved academic training for the ministry. That of the past has been narrowly ecclesiastical. There has been too much straight-jacket confinement to Bible study, systematic theology, and church history, with the consequence that the average pastor has been incapable of participating in the broader question of his time. There is, however, increased emphasis now being placed upon studies of a broader social and cultural nature. This must inevitably conduce to the development of a charitable, sympathetic, and more adaptable and versatile ministry. We need a ministry with not only a strictly acadamic training, but with preparation in various lines of social work. The religion of the future promises to be colored with ideals of social service. The successful pastor, therefore, will be he who is proficient in dealing with the social situation. And in addition to this, there is a crying need that every man preparing for the ministry be given a training in the principles of church administration. The future church, according to present indications, will make heavy demands upon the administrative ability of the pastor. Indeed, its success will depend largely upon the leadership, constructive powers, and perspicacity of the pastorate. The successful pastor will be the center of quickening

impulse of every leavening process that radiates from his church out into the world.

The equipment and program of the future country church will necessarily be somewhat different from those of the city church. There is a splendid impetus being given to the establishment of community houses in connection with country churches. In the absence of the means for providing an additional building, the church structure may be remodeled, especially its basement, in such a way as to adapt it to a more varied program. But the aim of every progressive organization should be the erection of a community house. Such a structure would preferably be furnace heated, and should have constant janitor service. Its construction would provide for a large upper room, to be used as an auditorium, and a lower room for parties, entertainments, and club meetings. There should be rooms sufficient in number to accommodate gymnasium classes, indoor games, and other features of the church program. A library, or reading room, is an essential which must under no circumstances be neglected. It is doubtful whether the rural church can offer, especially during the winter months, a greater attraction.

In general, the equipment of the church will depend upon the program to be followed. This should include, in addition to the usual devotional exercises, a variety of attractions, intended to appeal to all classes. The young people would be drawn particularly by the gymnasium, the games of basket-ball, indoor baseball, checkers, etc., the reading room, social gatherings, not to speak of numerous possible young people's clubs and associations. The women are usually more interested in sewing circles, reading groups, or classes in domestic science. For the men the best possible provisions would be night school, with classes for the study of branches of rural economy. Of especial benefit would be informal gatherings for the discussion of scientific farm operation and management. The auditorium would naturally be used for addresses, moving pictures, entertainments, and public meetings. In this connection a systematic effort would be made to secure speakers, lecturers, or demonstrators, to present topics of interest to rural society. The library embodies, as noted above, one of the great potentialities of the country church. There should be a working agreement among the churches to exchange books periodically, after the manner of public school traveling libraries. Otherwise the literature will be quickly perused and interest will begin to wane. One wonders why it is that thus far practically nothing has been done in this direction.

The object of the above described equipment and program would be to make the church a neighborhood center. Around it would be woven the life of the community. It should reach out, draw the interest of the

people its way, supply their needs, and reduce them to a feeling of dependence. When the populace has been drawn into this religious-social atmosphere, the work of evangelizing society may be said to have truly begun.

Such is the task of the future country church. Its very existence depends upon whether it accepts this responsibility. But there are signs in the times which lead one to think the awakening has already come. It is more in evidence perhaps among the progressive churches of our cities, for the cities have always led the way in up-to-date reform. But the spirit of criticism that is abroad today cannot long be deterred from spreading to the country. And so one must feel inclined to prophesy that the country church is about to be aroused to a renewed activity, which will eventually lead to a reestablishment in its rightful place as a leader in rural life.

University of Michigan.

# BOTANY.

# UNREPORTED MICHIGAN FUNGI FOR 1915 AND 1916, WITH AN INDEX TO THE HOSTS AND SUBSTRATA OF BASIDIOMYCETES.

BY C. H. KAUFFMAN.

The following plants have been added to the Cryptogamic Herbarium of the University from Michigan. Dr. Mains and Dr. Povah have communicated the rusts and mucors. Through the kindness of Prof. Burt a number of accumulated Thelephoraceae have been properly named.

It has seemed worth while to put on record also the data of many years concerning the distribution of the Basidiomycetes on the various hosts and woody substrata. These data are not by any means complete, but it will be seen that they extend very materially the distribution as so far given in our standard host indices. A large part of these data have been gathered by the senior class in forestry, who have annually collected at Ann Arbor and also on a trip to New Richmond, Mich., during the last six years. Some errors may have crept into the determinations of host, but in nearly all cases the material was checked by myself.

## PHYCOMYCETES.

### Entomophthoraceae.

*Entomophthora rhizospora* Thax. on caddis fly. Zygospore stage. Chippewa Co., Aug. Povah, fide Thaxter.

### Mucoraceae.

*Circinella spinosa* van Tieg. & le Monn. on decayed Brazil nut. Washtenaw Co., fide Povah.

*Mucor abundans* Povah. From dung and soil. Washtenaw Co., fide Povah.

*Mucor aromaticus* Povah. From dung, Washt. Co., fide Povah.

*Mucor christianiensis* Hagem. From greenhouse soil. Washt. Co., fide Povah.

*Mucor coprophilus* Povah. From rabbit's dung. Washt. Co., fide Povah.

*Mucor corticolus* Hagem. From soil. Washt. Co., fide Povah.

*Mucor griseo-cyaneus* Hagem. From dung. Washt. Co., fide Povah.

*Mucor griseo-lilacinus* Povah. From various kinds of dung. Washt. Co., fide Povah.

*Mucor griseosporus* Povah. From dung. Washt. Co., fide Povah.

*Mucor lamprosporus* Lendner. From oak roots. Washt. Co., fide Povah.

*Mucor plumbeus* Bonord. From Sphagnum with germinating seeds in Bot. lab. Ann Arbor, fide Povah.

*Mucor saturninus* Hagem. From horse dung. Washt. Co., fide Povah

*Mucor sphaerosporus* Hagem. From decayed leaves. Washt. Co., fide Povah.

*Mucor varians* Povah. From soil and decaying vegetable matter. Washt. Co., fide Povah.

*Rhizopus arrhizus* Fisch. Contamination in culture in lab. Ann Arbor, fide Povah.

*Zygorhynchus Vuilleminii* Namysl. From soil. Washt. Co., fide Povah.

*Glomerula repens* Bainier. From soil. Washt. Co., fide Povah.

**Peronosporaceæ.**

*Peronospora Arthuri* Farlow. On *Oenothera biennis.* Washt. Co., July 1., fide Mains.

*Peronospora trifoliorum* de Bary. On *Medicago sativa.* Washt. Co., May, fide Povah.

## ASCOMYCETES.

**Helvellaceæ.**

*Microglossum olivaceum* (Pers.) Gill. On the ground in frondose woods. Washt. Co., Aug., fide Mains.

**Pezizaceæ.**

*Geopyxis cupularis* Sacc. On humus. Washt. Co., June, fide C. H. K.

*Otidea phlebophora* (B. & Br.) Phillips. On the ground in low woods. Washt. Co., July, fide C. H. K.

*Plicaria pustulata* Fuckl. On soil in gardens, hot-beds, etc. Washt. Co., June-July, fide C. H. K.

**Mollisiaceæ.**

*Beloniella Dehnii* (Rabent.) Rehm. On *Potentilla monspeliensis.* Washt. Co., June, fide Mains.

*Pseudopeziza trifolii* (Bernh.) Fuckl. On *Trifolium repens.* Washt. Co., fide Mains.

**Cenangiaceæ.**

*Sarcosoma rufa* (Schw.) Rehm. On buried sticks. Washt. Co., fide C. H. K.

**Phacidiaceæ.**

*Phacidium repandum* Or. On Galium sp. Washt. Co., July, fide Mains.

**Hypodermataceae.**

*Hypoderma striaeformis* D. C. On stipe and rachis of *Pteris aquilina*. Washt. Co., May, fide Povah.

**Perisporiaceae.**

*Dimerosporium Ellisii* Sacc. On wintered leaves of Vaccinium. Washt. Co., May, fide Povah.

**Hypocreaceae.**

*Cordyceps herculea* (Schw.) Sacc. On larva of beetle. Washt. Co., Aug., fide Mains.

*Hypomyces chrysospermum* (Bull.) Tul. On Boletus sp. Washt. Co., Aug., fide Mains.

**Pleosporaceae.**

*Leptosphaeria Michotii* (West) Sacc. On Juncus sp. Washt. Co., May, fide Povah.

**Mycosphaerellaceae.**

*Mycosphaerella punctiformis* Pers. On wintered leaves of Quercus sp. Washt. Co., May, fide Mains.

**Massariaceae.**

*Massaria inquinans* Fr. On branches of Acer sp. Washt. Co., May, fide Mains. What appears to be a form of this was reported as *M. vomitaria*.

**Xylariaceae.**

*Hypoxylon tinctor* Berk. On elm log. New Richmond. Nov., fide C. H. K. The wood is colored red by the fungus.

BASIDIOMYCETES.

**Ustilaginaceae.**

*Cintractia Caricis* (Pers.) Magn. In ovaries of *Carex aquatilis*. Vermilion, (U. P.), July 28, Povah, fide Mains.

*Entyloma irregulare* Johans. On *Poa pratensis*. Washt. Co., fide Mains.

*Ustilago Heufleri* Tudd. On *Erythronium americanum*. Washt. Co., fide Mains.

**Uredinales.**

*Aecidium compositarum* Mart. var. *Silphii* Bron. On *Silphium integrifolium*. Washt. Co., fide Mains.

*Aecidium Clematitis* Schw. On *Clematis virginiana*. Washt. Co., May 24. Mary Goddard, fide Mains.

*Aecidium Lupini* Pk. On *Lupinus perennis*. Colon, Mich., May 27, fide C. H. K.

*Kuehneola Fici* (Cast.) Butler II. On *Ficus aurea* imported from Miami, Fla. in Univ. of Mich. greenhouses, fide Mains.

*Kuehneola uredinis* (Link) Arth. II. On *Rubus allegheniensis* etc. Ann Arbor, Coldwater, Oct., fide Mains.

*Melampsorella caryophyllacearum* Schroet. On *Stellaria longifolia*. Near Mud Lake, Whitmore. No signs of the other stage as no conifer witches brooms are known in the region. Found by W. A. Gardner, fide Mains.

*Puccinia antirrhini* Diet. & Holway II. On *Antirrhinum majus*. Detroit, May 29. Povah, fide Mains.

*Puccinia mesomegala* B. & C. III. On *Clintonia borealis*. Vermilion, (U. P.) Povah, fide Mains.

*Puccinia maculosa* Burr. On *Cynthia virginica*. Washt. Co., July, Mains, fide Arthur, "rare."

*Puccinia pygmaea* Erikss. II. On *Calamagrostis canadensis*. Washt. Co., Nov. 4, Povah, fide Mains.

*Puccinia tomipara* Trel. On *Bromus ciliatus*. Washt. Co., Mar. 18., Mains, fide Arthur.

*Puccinia Thalictri* Chev. II, III. (=*Polythelis Thalictri* (Chev.) Arth.) On *Thalictrum dioicum*. Douglas Lake. Aug. 10, F. B. Cotner, fide Mains.

*Peridermium balsameum* Pk. (III. *Uredinopsis mirabilis* (Pk.) Magn.) On *Abies balsamea*. Douglas Lake. F. B. Cotner, fide Mains.

*Uredinopsis Osmundae* Magn. II. On *Osmunda cinnamomea*. Vermilion. (U. P.) Povah, fide Mains.

*Uredinopsis Struthiopteridis* Störm II, III. On *Woodwardia virginica*. Washt. Co., Aug. 20, fide C. H. K.

*Uromyces Lilii* Clint. I. On *Lilium canadense*. Washt. Co., May 22, Mains, fide Arthur. Prof. Arthur writes: "The only other collection we have seen from Michigan was made by Holway in 1885 when the American Association met at Ann Arbor."

*Uromyces Rudbeckiae* Arth. & Holway. On *Rudbeckia laciniata*. Washt. Co., July 31. Mains, fide Arthur.

*Uromyces verruculosus* Schroet. On *Lychnis alba*. Douglas Lake. F. B. Cotner, fide Mains, "rare."

**Thelephoraceae.**

*Aleurodiscus amorphus* (Pers.) Rabenh. On dead twigs of *Abies balsamea*. Vermilion, (U. P.), July, Povah, fide Burt.

*Corticium albulum* Atk. & Burt. On decayed wood. Washt. Co., Nov. C. H. K., fide Burt.

*Corticium cremicolor* B. & C. On decayed wood. New Richmond, Nov. C. H. K., fide Burt.

*Corticium galactinum* (Fr.). On decayed log. Vermilion (U. P.), July. Povah, fide Burt.

*Corticium investiens* (Schw.) Burt. On wood. Washt. Co. and New Richmond, Nov. C. H. K., fide Burt.

*Corticium lactescens* Schw. On decayed wood. New Richmond, Nov. C. H. K., fide Burt.

*Corticium lacteum* Karst. On dead twig. Vermilion, (U. P.), July. Povah, fide Burt.

*Hypochnus subferrugineus* Burt. On decayed log. Washt. Co., Sept. Povah, fide Burt.

*Peniophora Burtii* Romell. On walnut wood. New Richmond, Sept. C. H. K., fide Burt.

*Peniophora incarnata* Fr. On dead branches of various trees. New Richmond and Ann Arbor., Oct.-Nov., fide C. H. K.

*Peniophora ludoviciana* Burt. On Black Ash sticks. Vermilion, (U. P.), Aug. Povah, fide Burt.

*Peniophora pinicola* Burt. On White Pine. New Richmond, Nov. C. H. K., fide Burt.

*Peniophora unicolor* Pk. On Beech wood. New Richmond, Sept. C. H. K., fide Burt.

*Peniophora velutina* (D. C.) Burt. On wood. New Richmond, Oct. C. H. K., fide Burt.

*Sebacina incrustans* Tul. (Syn. *Thelephora sebacea* Pers.) Spreading over mosses, grass, soil, etc., in woods and forming a whitish floccose layer. Washt. Co., Aug. C. H. K., fide Lloyd.

*Stereum erumpens* Burt. On *Prunus serotina*. Washt. Co., Nov. C. H. K., fide Burt.

*Thelephora albidobrunnea* Schw. On the ground near tamarack swamp. Washt. Co. Mains, fide Lloyd.

*Thelephora multipartita* Schw. On the ground. Washt. Co., fide C. H. K.

*Thelephora americana* Lloyd. On the ground in woods. Washt. Co., Aug. C. H. K., fide Lloyd.

**Hydnaceæ.**

*Hydnum vellereum* Pk (= *Hydnum amicum* Quel. per Lloyd). On ground in woods. Washt. Co., fide Lloyd.

*Odontia latitans* (Karst.). On conifer wood. Washt. Co. C. H. K., fide Burt.

*Odontia pruni* Lasch. On *Prunus serotina.* Washt. Co., Aug. C. H. K., fide Burt.

*Odontia setigera* (Fr.). On decayed wood. New Richmond, Nov. C. H. K., fide Burt.

*Odontia vesiculosa* Burt. On dead birch branch. Vermilion, (U. P.), July. Povah, fide Burt.

*Phlebia albida* Fr. On oak wood. New Richmond, Nov. C. H. K., fide Burt.

*Radulum Bennettii* B. & C. On birch bark. Vermilion, (U. P.). Povah, fide Burt.

*Radulum pallidum* B. & C. On sticks, New Richmond, Ann Arbor. C. H. K., fide Burt.

## Polyporaceæ.

*Merulius aureus* Fr. On wood of *Pinus Strobus.* New Richmond, Nov. C. H. K., fide Burt.

*Merulius bellus* B. & C. On sticks of *Pinus Strobus,* New Richmond, Sept. C. H. K., fide Burt.

*Polyporus alboluteus* (Ellis). On decayed conifer log. Vermilion, (U. P.), Aug. Povah, fide Lloyd.

*Polyporus fragilis* Berk. On fallen branches of *Pinus Strobus.* New Richmond., Nov. C. H. K., fide Lloyd.

## Sclerodermataceæ.

*Scleroderma tenerum* Berk. In woods. Washt. Co., July, fide Lloyd.

### FUNGI IMPERFECTI.

*Cercospora Maianthemi* Fuckl. On *Maianthemum canadensis.* Washt. Co., May, fide Mains.

*Cladosporium Typharum* Desm. On *Typha latifolia.* Washt. Co., Oct., fide Povah.

*Leptostroma aquilinum* Mass. On *Pteris aquilina.* Washt. Co., May, fide Povah.

*Ovularia obliqua* (Cke) Oud. (Perfect stage=*Mycosphaerella rumicis).* On Rumex crispa. Washt. Co., May, fide Mains.

*Pestalozzia montellica* Sacc. On fallen leaves of Quercus sp. Washt. Co., May, fide Mains.

*Ramularia Ranunculi* Pk. On *Ranuculus recurvatus.* Washt. Co., May, fide Mains.

# INDEX TO THE HOSTS AND WOODY SUB-STRATA OF HYMENOMYCETES IN MICHIGAN.

## APPLE (*Pirus Malus*).

*Fomes applanatus* Fr.
*Fomes pinicola* Fr.
*Polyporus adustus* Fr.
*Polyporus fumosus* Fr.
*Polyporus benzoinus* Fr.
*Polystictus hirsutellus* Schw.
*Polystictus hirsutus* Fr.
*Polystictus versicolor* Fr.
*Daedalea confragosa* Fr.
*Daedalea unicolor* Fr.
*Irpex tulipiferae* (Schw.) Fr.
*Lenzites betulina* Fr.
*Schizophyllum commune*, Fr.
*Panus strigosus* B. & C.
*Pleurotus ulmarius* Fr.
*Pholiota adiposa* Fr.
*Hydnum croceum*.
*Hydnum mucidum* Pk.
*Stereum cinerascens* (Schw.).
*Peniophora cinerea* (Fr.) Cke.

## ALDER (*Alnus*).

*Fomes igniarius* Fr.
*Fomes scutellatus* Fr.
*Polyporus radiatus* Fr.
*Polyporus lacteus* Fr.
*Polystictus velutinus* Fr.
*Irpex tulipiferae* (Schw.) Fr.
*Trogia crispa* Fr.
*Stereum hirsutum* Fr.
*Peniophora cinerea* Fr.
*Peniophora incarnata* Fr.

## ASH (*Fraxinus*)

*Fomes applanatus* Fr. (live).
*Fomes conchatus* Fr.
*Fomes fraxineus* Fr.
*Fomes fraxinophilus* Pk. (live).
*Polyporus cuticularis* Fr.
*Polyporus fumosus* Fr.
*Poria inermis* E. & E.
*Poria salmonicolor* E. & E.
*Poria semitincta* Pk.
*Trametes sepium* Fr.
*Irpex tulipiferae* (Schw.) Fr.
*Daedalea confragosa* Fr.
*Polyporus hispidus* Fr. (live).
*Polyporus picipes* Fr.
*Polyporus spumeus* Fr.
*Polyporus sulphureus* Fr.
*Polystictus biformis* Fr.
*Polystictus hirsutus* Fr.
*Polystictus pubescens* Fr.
*Polystictus versicolor* Fr.
*Schizophyllum commune* Fr.
*Pleurotus serotinus* Fr.
*Phlebia radiata* Fr.
*Stereum cinerascens* (Schw.)
*Corticium vellereum* Ell. & Crag.
*Peniophora cinerea* Fr.
*Peniophora incarnata* Fr.
*Peniophora ludoviciana* Burt.

## BASSWOOD (*Tilia americana*).

*Fomes applanatus* Fr.
*Fomes conchatus* Fr.
*Polyporus arcularius* Fr.
*Polyporus adustus* Fr.
*Polyporus benzoinus* Fr.
*Polyporus brumalis* Fr.
*Polyporus fumosus* Fr.
*Polyporus gilvus* Fr.
*Trametes sepium* Fr.
*Irpex mollis* B. & C.
*Gloeoporus dichrous* (Fr.).
*Schizophyllum commune* Fr.
*Merulius tremulosus* Fr.
*Corticium vellereum* Ell. & Crag.
*Peniophora Allescheri* Bres.

BEECH (*Fagus grandifolia*).

*Fomes applanatus* Fr. (live).
*Fomes fomentarius* Fr.
*Fomes Everhartii* Ell. & Galloway (live).
*Fomes igniarius* Fr. (live).
*Polyporus arcularius* Fr.
*Polyporus benzoinus* Fr.
*Polyporus biformis* Fr.
*Polyporus cuticularis* Fr.
*Polyporus gilvus* Fr.
*Polyporus rutilans* Fr.
*Daedalea unicolor* Fr.
*Irpex mollis* B. & C.
*Irpex cinnamomeus* Schw.
*Irpex tulipiferae* (Schw.) Fr.
*Gloeoporus dichrous* (Fr.).
*Favolus europaeus* Fr.
*Merulius tremulosus* Fr.
*Lenzites betulina* Fr.
*Schizophyllum commune* Fr.
*Hydnum caput-ursae* Fr.
*Hydnum coralloides* Fr.
*Polyporus semipileatus* Fr.
*Polyporus sulphureus* Fr. (live).
*Polystictus hirsutus* Fr.
*Polystictus pergamenus* Fr.
*Polystictus pubescens* Fr.
*Polystictus versicolor* Fr.
*Poria ambigua* Bres.
*Trametes sepium* Fr.
*Daedalea confragosa* Fr.
*Phlebia radiata* Fr.
*Stereum fasciatum* Schw.
*Stereum rameale* Schw.
*Stereum sericeum* Schw.
*Stereum spadiceum* Fr.
*Stereum versicolor* Fr.
*Peniophora viticola* (Schw.) Burt.
*Peniophora unicolor* Pk.

BIRCH (*Betula lutea*).

*Fomes applanatus* Fr. (live).
*Fomes fomentarius* Fr.
*Fomes nigricans* Fr.
*Fomes pinicola* Fr.
*Fomes igniarius* Fr.
*Polyporus arcularius* Fr.
*Polyporus biformis* Fr.
*Polyporus radiatus* Fr.
*Polyporus rutilans* Fr.
*Polystictus pergamenus* Fr.
*Polystictus pubescens* Fr.
*Polystictus versicolor* Fr.
*Poria subacida* Pk.
*Trametes cinnabarina* Fr.
*Trametes sepium* Fr.
*Favolus europaeus* Fr.
*Gloeoporus dichrous* (Fr.).
*Daedalea confragosa* Fr.
*Daedalea unicolor* Fr.
*Irpex lacteus* Fr.
*Irpex tulipiferae* (Schw.) Fr.
*Merulius tremulosus* Fr.
*Lenzites betulina* Fr.
*Trogia crispa* Fr.
*Panus stipticus* Fr.
*Pleurotus ostreatus* Fr.
*Pleurotus serotinus* Fr.
*Phlebia radiata* Fr.
*Stereum tuberculosum* Fr.

CEDAR (*Thuja occidentalis*).

*Polyporus aurantiacus* Pk.
*Polyporus hirtus* Quel. (*P. hispidellus* Pk.).
*Trametes carneus* Fr.
*Trametes serpens* Fr.

CHERRY *(Prunus serotina).*

*Fomes pinicola* Fr. (live).
*Polyporus chioneus* Fr.
*Polyporus gilvus* Fr.
*Polyporus rutilans* Fr.
*Polystictus hirsutus* Fr.
*Polystictus pubescens* Fr.
*Polystictus pergamenus* Fr.
*Polystictus versicolor* Fr.
*Trametes cinnabarina* Fr.
*Daedalea confragosa* Fr.
*Irpex lacteus* Fr.
*Irpex tulipiferae* (Schw.) Fr.
*Trogia crispa* Fr.
*Schizophyllum commune* Fr.
*Phlebia radiata* Fr.
*Phlebia strigosozonata* Fr.
*Grandinia corrugata* Fr.
*Stereum erumpens* Burt.
*Corticium cremicolor* V. & C.
*Peniophora cinerea* Fr.

ELM *(Ulmus)* MOSTLY *U. americana.*

*Fomes applanatus* Fr. (live).
*Fomes connatus* Fr.
*Fomes conchatus* Fr.
*Polyporus albellus* Pk.
*Polyporus arcularius* Fr.
*Polyporus benzoinus* Fr.
*Polyporus galactinus,* Berk.
*Polyporus gilvus* Fr.
*Polyporus picipes* Fr.
*Polyporus sessilis* Murr.
*Polyporus Spraguei* B. & C.
*Polyporus squamosus* Fr.
*Polystictus conchifer* Schw.
*Polystictus hirsutus* Fr.
*Polystictus zonatus* Fr.
*Poria ferruginosa* Fr.
*Poria attenuata* Pk.
*Poria salmonicolor* Pk.
*Favolus europaeus* Fr.
*Gloeoporus dichrous* (Fr.)
*Lenzites betulina* Fr.
*Schizophyllum commune* Fr.
*Lentinus tigrinus* Fr.
*Pleurotus ostreatus* Fr. (live).
*Pleurotus serotinus* Fr.
*Pleurotus ulmarius* Fr. (live).
*Pholiota adiposa* Fr. (live).
*Stereum cinerascens* (Schw.)
*Stereum rameale* Schw.
*Corticium lactescens* Schw.
*Corticium vellereum* Ell. & Crag.
*Peniophora Allescheri* Bres.

FIR *(Abies balsamea).*

*Polystictus abietinus* Fr.
*Trametes Pini* Fr.

HAWTHORN *(Craetaegus).*

*Poria inermis* E. & E.
*Peniophora cinerea* Fr.

HEMLOCK *(Tsuga canadensis).*

*Fomes pinicola* Fr.
*Fomes annosus* Fr.
*Polyporus fumosus* Fr.
*Polyporus guttulatus* Pk.
*Polyporus lucidus* Fr.
*Polyporus resinosus* Fr.
*Polyporus Weinmanni* Fr.
*Polystictus abietinus* Fr.
*Poria ferruginosa* Fr.
*Porothelium fimbriatum* Fr.
*Trametes Pini* Fr.
*Merulius lacrymans* Fr.
*Lenzites sepiaria* Fr.
*Stereum frustulosum* Fr.

HICKORY *(Carya).*

*Fomes connatus* Fr.
*Polyporus rutilans* Fr.
*Trametes sepium* Fr.
*Favolus europaeus* Fr.
*Irpex cinnamomeus* Fr.
*Irpex tulipiferae* (Schw.) Fr.
*Schizophyllum commune* Fr.
*Pleurotus ulmarius* Fr.
*Stereum fasciatum* Schw.
*Stereum spadiceum* Fr.
*Stereum rameale* Schw.
*Peniophora cinerea* Fr.

HOP HORNBEAM *(Ostrya virginiana).*

*Fomes igniarius* Fr.
*Polyporus adustus* Fr.
*Polystictus versicolor* Fr.
*Daedalea confragosa* Fr.
*Daedalea unicolor* Fr.
*Stereum "versicolor."*
*Aleurodiscus Oakesii* B. & C.

HORNBEAM *(Carpinus carolinianus).*

*Fomes igniarius* Fr.
*Polyporus arcularius* Fr.
*Polyporus gilvus* Fr.
*Polystictus hirsutus* Fr.
*Polystictus sericeus* Fr.
*Polystictus versicolor* Fr.
*Trametes sepium* Fr.
*Irpex tulipiferae* Schw.
*Hydnum ochraceum* Fr.
*Phlebia radiata* Fr.
*Stereum purpureum* Fr.
*Stereum rameale* Schw.
*Stereum sericeum* Fr.
*Stereum cinerascens* ( Schw.)
*Peniophora cinerea* Fr.
*Aleurodiscus Oakesii* B. & C.

LOCUST *(Robinia Pseudacacia).*

*Polyporus robiniophila* (Murr.).
*Peniophora incarnata* Pk.

MAPLE *(Acer).*

*Fomes applanatus* Fr.
*Fomes connatus* Fr.
*Fomes ohiense* Berk.
*Fomes pinicola* Fr.
*Polyporus adustus* Fr.
*Polyporus aurantiacus* Pk.
*Polyporus benzoinus* Fr.
*Polyporus caesius* Fr.
*Polyporus cuticularis* Fr.
*Polyporus gilvus* Fr.
*Polyporus glomeratus* Pk.
*Polyporus picipes* Fr.
*Polyporus rutilans* Fr.
*Polyporus sessilis* (Murr.)
*Polyporus sulphureus* Fr.
*Polyporus spumeus* Fr.
*Polystictus biformis* Klotsch
*Irpex tulipiferae* Schw.
*Lenzites betulina* Fr.
*Schizophyllum commune* Fr.
*Pleurotus ostreatus* Fr. (live).
*Pleurotus ulmarius* Fr. (live).
*Pleurotus corticatus* Fr.
*Pholiota adiposa* Fr. (live).
*Merulius tremulosus* Fr.
*Hydnum caput-ursae* Fr.
*Hydnum ochraceum* Fr.
*Hydnum septentrionale* Fr.
*Odontia fimbriata* Fr.
*Stereum fasciatum* Schw.
*Stereum ochraceoflavum* Schw.
*Polystictus pubescens* Fr.
*Trametes cinnabarina* Fr.
*Trametes sepium* Fr.

*Polystictus pergamenus* Fr.
*Favolus europaeus* Fr.
*Gloeoporus dichrous* (Fr.)
*Irpex cinnamomeus* Fr.
*Irpex mollis* B. & C.
*Daedalea confragosa* Fr.
*Stereum rameale* Schw.
*Stereum rugosum* Fr.
*Stereum spadiceum* Fr.
*Stereum tuberculosum* Fr.

OAK (*Quercus*).

*Fomes applanatus* Fr. (live).
*Fomes conchatus* Fr.
*Fomes Everhartii* Ell. & Galloway
*Fomes ohiense* Berk.
*Polyporus albellus* Pk.
*Polyporus adustus* Fr.
*Polyporus arcularius* Fr.
*Polyporus croceus* Fr.
*Polyporus fumosus* Fr.
*Polyporus gilvus* Fr.
*Polyporus lacteus* Fr.
*Polyporus radicatus* Schw.
*Polyporus Rheades* Fr. (= P. dryophilus Fr.).
*Polyporus rutilans* Fr.
*Polyporus Spraguei* Berk.
*Polyporus sulphureus* Fr.
*Polystictus conchifer* Schw.
*Polystictus pergamenus* Fr.
*Polystictus versicolor* Fr.
*Poria ambigua* Bres.
*Poria attenuata* Pk.
*Poria nitida* (A. & S.).
*Poria pulchella* Schw.
*Trametes cinnabarina* Fr.
*Trametes Peckii* Kalchb.
*Daedalea confragosa* Fr.
*Daedalea unicolor* Fr.
*Favolus europaeus* Fr.
*Irpex cinnamomeus* Fr.
*Irpex mollis* B. & C.
*Irpex tulipiferae* (Schw.) Fr.
*Merulius tremulosus* Fr.
*Lenzites betulina* Fr.
*Schizophyllum commune* Fr.
*Trogia crispa* Fr.
*Panus stipticus* Fr.
*Hydnum ochraceum* Fr.
*Phlebia albida Fr.*
*Phlebia radiata* Fr.
*Odontia alutacea* Fr.
*Odontia fimbriata* Fr.
*Stereum fasciatum* Schw.
*Stereum frustulosum* Fr.
*Stereum ochraceo-flavum* Schw.
*Stereum rameale* Schw.
*Stereum spadiceum* Fr.
*Stereum versicolor* Fr.
*Hymenochaete tabacina* Fr.
*Corticium albulum* Atk. & Burt.

PINE (*Pinus Strobus*).

*Polyporus Weinmanni* Fr. (=P. mollis Fr.).
*Polyporus fragilis* Fr.
*Polyporus Schweinitzii* Fr.
*Polystictus abietinus* Fr.
*Polystictus versicolor* Fr.
*Trametes Pini* Fr.
*Merulius aureus* Fr.
*Merulius bellus* B. & C.
*Merulius tremulosus* Fr.
*Lenzites sepiaria* Fr.
*Hydnum subfuscum* Pk.
*Grandinia cylindrica* Burt.
*Stereum spadiceum* Fr.
*Stereum sanguinolentum* Fr.
*Corticium investiens* Bres.
*Corticium subcontinuum* B. & C.
*Coniophora puteana* B. & C.
*Peniophora gigantea* Fr.
*Peniophora pinicola* Burt.

POPLAR (*Populus*).

*Fomes igniarius* Fr.
*Fomes fomentarius* Fr.
*Fomes pinicola* Fr.
*Polyporus adustus* Fr.
*Polyporus fumosus* Fr.
*Polyporus gilvus* Fr.
*Polyporus lacteus* Fr.
*Polyporus rutilans* Fr.
*Polystictus biformis* Klotsch.
*Polystictus hirsutus* Fr.
*Polystictus pubescens* Fr.
*Polystictus pergamenus* Fr.
*Poria attenuata* Pk.
*Poria ferruginosa* Fr.
*Trametes cinnabarina* Fr.
*Trametes Peckii* Kalchb.
*Trametes protracta* Fr.
*Irpex cinnamomeus* Fr.
*Irpex tulipiferae* (Schw.) Fr.
*Favolus europaeus* Fr.
*Gloeoporus dichrous* (Fr.).
*Merulius tremulosus* Fr.
*Schizophyllum commune* Fr.
*Trogia crispa* Fr.
*Hydnum ochraceum* Fr.
*Hydnum Kauffmani* Pk.
*Phlebia radiata* Fr.
*Phlebia strigosozonata* Fr.
*Stereum cinerascens* (Fr.).
*Stereum sericeum* Fr.
*Stereum versicolor* Fr.
*Corticium bombycinum* Fr.
*Corticium perzizoideum*.
*Corticium salicinum* Fr.
*Daedalea confragosa* Fr.
*Daedalea unicolor* Fr.
*Irpex cinnamomeus* Fr.
*Corticium vellereum* Ell. & Crag.
*Peniophora allescheri* Bres.
*Peniophora laevis* Fr.

SASSAFRAS (*Sassafras variifolium*).

*Fomes igniarius* Fr.
*Fomes conchatus* Fr.
*Poria ferruginosa* Fr.
*Poria inermis* E. & E.
*Trametes sepium* Fr.
*Daedalea confragosa* Fr.
*Irpex tulipiferae* (Schw.) Fr.
*Schizophyllum commune* Fr.

SPRUCE (*Picea*).

*Fomes roseus* (A. & S.).
*Polyporus Weinmanni* Fr.
*Trametes Pini* Fr.
*Asterostroma corticolum* Mass.

SYCAMORE (*Platanus occidentalis*).

*Polyporus fumosus* Fr.
*Polyporus gilvus* Fr.
*Polystictus pergamenus* Fr.
*Polystictus versicolor* Fr.
*Poria purpurea* Fr.
*Poria subacida* Pk.
*Lentinus tigrinus* Fr.
*Hydnum coralloides* Fr.

TULIP TREE (*Liriodendron tulipifera*).

*Irpex tulipiferae* (Schw.) Fr.
*Phlebia radiata* Fr.

TAMARACK (*Larix occidentalis*).

*Fomes pinicola* Fr.
*Polyporus floriformis* Quel.
*Polyporus Schweinitzii* Fr.
*Trametes Pini* Fr.
*Poria subacida* Pk.
*Merulius subaurantiacus* Pk.
*Stereum radiatum* Pk.
*Corticium lacteum* Fr.
*Corticium vellereum* Ell. & Crag.

WALNUT AND BUTTERNUT *(Juglans)*.

*Fomes conchatus* Fr.
*Poria inermis* E. & E.
*Peniophora Burtii* Romell.

WILLOW *(Salix)*.

*Fomes applanatus* Fr.
*Fomes conchatus* Fr.
*Fomes igniarius* Fr.
*Polyporus albellus* Pk.
*Polyporus adustus* Fr.
*Polyporus benzoinus* Fr.
*Polyporus fumosus* Fr.
*Polyporus lacteus* Fr.
*Polyporus picipes* Fr.
*Polyporus squamosus* Fr.
*Polystictus hirsutus* Fr.
*Polystictus pergamenus* Fr.
*Polystictus versicolor* Fr.
*Poria inermis* E. & E.
*Poria ferruginosa* Fr.
*Poria medullae-panis* Fr.
*Daedalea confragosa* Fr.
*Schizophyllum commune* Fr.
*Pleurotus ostreatus* Fr.
*Pleurotus ulmarius* Fr.
*Peniophora cinerea* Fr.

# MICHIGAN COLLECTIONS OF MYXOMYCETES.

BY H. C. BEARDSLEE.

The list which accompanies this is the record of species of Myxomycetes collected in Montmorency Co., Mich., during August in two different summers. It will be found to be incomplete on account of the short duration of the collecting season. A number of species which may reasonably be expected in the region studied were not detected. Some of these may possibly have appeared later in the season.

Of the species found a few seem of especial interest. *Physarum diderma Rost.* and *P. leucopus* Link are both very rare. Both are so distinct and the material so good that there can be no doubt of the identity of the specimens found.

It has seemed best to use the nomenclature of Macbride's Manual.

*Fuligo ovata* (Schaeff.) Macbr. Common.

*Physarum sinuosum* (Bull.) Weinm.
On old sticks. Common.

*Physarum diderma* Rost.
This species seems to have been detected few times. It is one of the most distinct and beautiful of our species. In my specimens the double peridium, with the outer layer pure white, seemed at first sight to belong to Diderma. The capillitium is, however, clearly that of Physarum. It was found only once.

*Physarum contextum* Pers.
On fallen twigs and stipes of ferns.

*Physarum virescens* Ditm.
On old logs, not rare.

*Physarum cinereum* (Batsch) Pers.
On blades of grass. Often in rings.

*Physarum plumbeum* Fries.
On old leaves.

*Physarum atrum* Schw.
My specimens are in close accord with some from Pennsylvania. They are close to other species of this genus, but seem distinct.

19th Mich. Acad. Sci. Rept., 1917.

*Physarum nefroideum* Rost.
Growing in large colonies on old logs. This was probably the most abundant and variable of the species of Physarum detected. My material includes the forms considered *P. connexum* and *P. leucophaeum* by Morgan.

*Physarum globuliferum* (Bull.) Pers.
On old logs.

*Physarum leucopus* Link.
This seems to have been detected in few localities. My specimens were found growing on old leaves. The snow white stipe gives it much the appearance of *Didymium squamulosum*.

*Physarum rufipes* (A. & S.) Morgan.
On old logs.

*Physarum flavicomum* Berk.
Found once on old logs.

*Physarum lateritium* (B. & Br.) Rost.
Found only once.

*Tilmadoche polycephala* (Schw.) Macbr.
In large colonies on old logs. Not rare.

*Tilmadoche alba* (Bull.) Macbr.
On old logs. Common.

*Tilmadoche viridis* (Bull.) Saccardo.
Common and very variable in color.

*Tilmadoche compacta* Wingate.
On old logs.

*Physarella oblonga* (B. & C.) Morgan.
In large colonies on logs.

*Craterium aureum* (Schum.) Rost.
The sporangium in my specimens was pyriform and bright yellow. At maturity it breaks in such a way as to leave a distinct cup, but one of more irregular shape than is characteristic of the other species of this genus.

*Craterium leucocephalum* (Pers.) Ditmar.
This species was by far the most abundant of the genus. The closely related species *C. minimum* B. & C. which is the characteristic species of northern Ohio was not observed. The brown sporangia, and pure white, irregularly circumcissile cap distinguish it.

*Craterium minutum* (Leers) Fries.
On old leaves. Common.

*Didymium squamulosum* (A. & S.) Fries.

On old leaves. Common.

*Didymium melanospermum* (Pers.) Macbr.

Very common. My specimens were very variable and seemed to run into the following species in such a way as to make the separation of the two species difficult.

*Didymium minus* Lister.

Common.

*Didymium xanthopus* (Ditm.) Fries.

Common on old leaves.

*Diderma reticulatum* (Rost.) Morgan.

On old leaves.

*Diderma spumarioides* Fr.

*Diderma testaceum* (Schrad.) Pers.

Common.

*Lepidoderma tigrinum* (Schrad.) Rost.

This interesting species was found once only. It is apparently rare.

*Stemonitis maxima* Schw.

Common.

*Stemonitis Morgani* Pk.

Frequent.

*Stemonitis Smithii* Macbr.

The forms collected included the small form corresponding well to the ones originally described as *S. Smithii* Macbr. as well as forms which were considered *S. microspora* by Morgan. All agree in the small, smooth spores.

*Comatricha irregularis* Rex.

This was found to be quite common on old logs. If it occurs in the collecting grounds in northern Ohio with which I am familiar it is rare, certainly much less abundant than it is in northern Michigan.

*Comatricha stemonitis* (Scop.) Sheldon.

Common and typical.

*Diachea leucopoda* (Bull.) Rost.

Abundant everywhere.

*Lamproderma arcyrionema* Rost.

The species of Lamproderma detected were few in number. One collection seemed to be *L. violaceum* but the scanty material was unsatisfactory.

*Enteridium splendens* Morgan.
Rather common.

*Tubifera ferruginosa* (Batsch) Macbr.
Common.

*Cribraria argillacea* Pers.
Rare. My collections were found in one place and were rather scanty.

*Cribraria dictydioides* C. & B.
Abundant.

*Dictydium cancellatum* (Batsch) Macbr.
Common.

*Lycogala epidendrum* (Buxb.) Fries.
Common.

*Arcyria nutans* (Bull.) Grev.
Rather common.

*Arcyria incarnata* Pers.

*Arcyria denudata* (Linn.) Sheldon.

*Arcyria cinerea* (Bull.) Pers.

*Arcyria digitata* (Schw.) Rost.

*Hemitrichia serpula* (Scop.) Rost.

*Hemitrichia vesparium* (Batsch) Macbr.

*Hemitrichia clavata* (Pers.) Rost.

*Trichia inconspicua* Rost.
Rare during the summer months. My specimens compare well with collections from Ohio and North Carolina.

*Trichia scabra* Rost.
On old logs. Common.

*Trichia persimilis* Karst.

*Oligonema flavidum* (Peck) Mass.
Asheville School, Asheville, N. C.

# PHYSIOLOGICAL BALANCE IN THE SOIL SOLUTION.

BY R. P. HIBBARD.

Considerable interest has been aroused in the subject of the mineral requirement of plants by two comparatively recent publications. I refer to the work of Tottingham[1] and to that of Shive[2]. These investigators have shown among other interesting facts that within certain limits there is an optimum proportion of salts, a certain best physiological balance of salts in a culture solution. They have each further shown that this physiological balance is dependent on the total concentration of salts in the solution. When the total concentration is .6% or about 2.50 atmospheres of pressure, for example, the optimum proportion of salts is different from that when the total concentration is .2% or .85 atmospheres of pressure. This is in conformation of the conclusion obtained by both Gile[3] and McCool[4] concerning the antitoxic effect of calcium in overcoming the toxicity due to different concentrations of magnesium. The ratio of lime to magnesium varies with the total concentrant of the solution.

Tottingham used Knop's four salt solution containing $MgSO_4$, $KNO_3$, $Ca(NO_3)_2$, $KH_2PO_4$, together with a few drops of a uniform suspension of ferric phosphate. Such a solution contains all the essential elements and fills the requirement demanded by all mineral requirement investigators. Shive made an improvement in the method of culture solution by eliminating the salt $KNO_3$. This did not take out any of the essential elements since potassium is present in $KH_2PO_4$ and the nitrate in $Ca(NO_3)_2$. In order to find out the effect of the various salts ratios possible when each proportion varied by increments of one-tenth of the total concentration while using four different salts there was need of 84 different culture solutions. When the three salt solution is considered the number of cultures is reduced to 36. The Shive solution is eminently suitable for wheat, oats and field and garden peas for the first few weeks of growth according to studies in this laboratory.

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19th Mich. Acad. Sci. Rept., 1917.

[1]Tottingham, W. E.—A quantitative chemical and physiological study of nutrient solutions for plant cultures. Physiol. Res. 1; 183-245, 1914.

[2]Shive, J. W.—A study of physiological balance in nutrient media. Physiol. Res. 1: 327-397, 1915.

[3]Gile, P. L.—Lime magnesia ratio as influenced by concentration, Porto Rico Agric. Exp. Sta., Bull. 12.

[4]McCool, M. M.—The action of certain nutrient and non-nutrient bases on plant growth. Cornell Agric. Exp. Sta. Mem. 2; 121-170, 1913.

In the studies of Shive and Tottingham the cultures were made up with distilled water and pure chemicals. We have repeated this work with close agreement to their results. The work has been further extended to include studies of the physiological balance in soil solution, in sand cultures and in soil cultures. Some of the main points in our studies on the physiological balance in soil solutions are to be reported here.

The soil solution used in these studies was obtained from selected samples of soil by the oil pressure method devised by Dr. van Suchtelin and more recently perfected and extended in its usefulness by Mr. Morgan[5] of the Bacteriological Laboratory, Michigan Agricultural College.

The stock solutions of the three salts were made up separately in $\frac{M}{4}$ concentration using the soil solution instead of distilled water as is the usual custom. A fourth-molecular solution was selected since at this dilution no precipitate appears for the period that the stock solutions are needed. Oven dried salts were used. The bottles containing the stock solutions were fitted up with the necessary burettes, glass and rubber tubing to facilitate the tedious operation of making a culture solution. The method was as follows:

A 250 cc. volumetric flask was filled about two-thirds full of soil solution, then to this was added separately with frequent shaking, the various amounts of the stock solutions as required. The flask was then filled up to the mark with soil solution. The three salts were added so as to make up a concentration of 1.75 atmospheres of pressure or about .4%. The soil solution had a pressure of .220 so that the total concentration was 1.97, approximately 2. atmospheres. This final concentration was determined by the cryoscopic method. In a series of solutions having three constituents the relative proportion of these three salts may be varied to give a great number of solutions, and still the total concentration will remain the same. In this particular case the variation in the proportion of salts was by increments of one-tenth the total concentration. All the possible combinations would give a series of thirty-six cultures.

These cultures fill the requirements necessary; first they are all at the same total osmotic concentration, second, the ratios of salts in every culture differs from the others by increment of one-tenth the total concentration, third, each culture solution contains the essential elements. Under such conditions it would seem possible to find the one best culture or optimum physiological balance.

The soil solutions obtained from various soils by the oil pressure method show characteristic differences when considered from physical,

[5]Morgan, J. F.—The soil solution obtained by the oil pressure method. Soil Science, Vol. III, No. 6: 531-546, 1917.

chemical and biological points of view. These data have appeared in a previous bulletin[6]. In order to find out if any possible benefit could be derived from any addition of salts in definite proportions the soil solutions were treated with the 36 different combination of three salts, these three salts being $KH_2PO_4$, $Ca(NO_3)_2$, and $MgSO_4$. By this method it would seem to be possible to determine what a particular soil lacks, and what treatment it needs to improve it. Below is reported very briefly the results obtained with a solution extracted from an infertile soil and another solution pressed from a fertile soil.

To the different soil solutions was added the three salts in the various ratios as described above. As indicators to determine the relative values of the various cultures, seedlings of winter wheat were used. At the same time that the series on the soil solution of the poor soil was run, there was a similar series made up with distilled water for comparison. After about four weeks growth the plants were harvested and the dry weights determined. The data for the dry weight of tops are mentioned here only. Besides these, data were collected on transpiration, water requirement, evaporating power of the air, and dry weight of roots. In the distilled water series the culture solution which gave the highest dry weight was the solution designated as 523. This means that five-tenths of the total concentration was from the $KH_2PO_4$, two-tenths from the $Ca(NO_3)_2$ and three-tenths from the $MgSO_4$. In the case of the cultures made up with the soil solution the best result was in culture designated as 712—seven-tenths of the concentration was made up of $KH_2PO_4$, one-tenth of $Ca(NO_3)_2$ and two-tenths of $MgSO_4$. By comparing these two results an interesting fact can be brought to light. Taking 523 as normal it is readily seen, that the soil solution needed more than the five-tenths of $KH_2PO_4$. In fact it needed seven-tenths. It follows then that the soil solution lacked K and $P_2O_5$. In addition it had about the right ratio of Ca and N and about the right amount of Mg and S. A chemical analysis of the original soil solution showed that it was poor in K and $P_2O_5$. In regard to the Ca, N, Mg and S the results of the chemical analysis and the needs of the soil did not compare so well. It appears that it will be possible in this way to find out the needs of the soil. It is further necessary to grow seedlings in this poor soil to which has been added a certain definite amount of $KH_2PO_4$ to supply the lack. If the seedlings do better here than in the soil without $KH_2PO_4$ treatment it would seem that something of value had been obtained. This work has not yet been completed. The above experiment has been repeated with soil solutions obtained from a good sandy loam soil. The result showed that the best salt proportion was that designated

[6]Morgan, J. F.—The soil solution obtained by the oil pressure method. Soil Science, Vol. III, No. 6; 531-546, 1917.

as 271. In this case there was more K and $P_2O_5$ than required. The same may be said of Mg and S. However, this soil needs more lime. In this particular experiment the total concentration was quite high. When this was lowered to about 2 atmospheres the same concentration as that of the poor soil solution the ratio of salts was 168. This showed that the soil needed liming also and had more K and $P_2O_4$ than required. The original soil has been treated with $Ca(NO_3)_2$ and planted with wheat. This work still awaits completion.

The study outlined above has so far shown that with soil solutions as well as with distilled water cultures there is an optimum or best proportion of salts in which the test plants grow better than in any other. It also shows as especially indicated in case of the good soil solution that at different concentrations the optimum ratio of salts differs. It is further believed that by this method of study we can get an indication of the needs of the soil and so finally obtain a clearer understanding of the soil fertilization requirements. It would seem quite feasible to devise a rational system of fertilization from the standpoint of balanced solutions.

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# THE RELATION BETWEEN TEMPERATURE AND CROPS.

DEWEY ALSDORF SEELEY.

Temperature is one of the most influential of all the climatic conditions affecting plant growth and at the same time one of the most difficult to study. Numerous investigators, beginning as far back as 1735, have attacked the problem but we are still without a satisfactory statement of the relationship between the air temperature and the development of a single farm crop, due largely to the fact that there are so many complicated influences involved. We do not know, for example, at what temperature a crop of wheat will thrive best, from seeding to harvest, nor the number of days with a yet undetermined optimum temperature for growth, that is required for the plant to pass through its life history To be sure tests have been made in the laboratory on wheat, corn, etc., to find the growth rate of seedlings, and the minimum, optimum and maximum temperatures at which development proceeds have been determined. But the experiments have not been continued to cover the entire life history, nor have the effects of varying insolation, humidity, wind velocity, etc., surrounding the plant in the open, been taken fully into consideration, as to their influence on temperature and growth rate.

The fruit trees blossom in the spring after a period of warm weather, and then after another period, with much more heat, the fruit comes to maturity and ripens. But no one has yet stated the relationship between the temperature of the air and either of the life processes mentioned, except in the most general terms. No one has been able to determine in advance before the coming of spring, how many days with given ranges of temperature will pass before apples or peaches blossom.

It is almost self-evident that an immense advantage to agriculture would result if the heat requirements of various crops could be determined and stated in terms of air temperature and time. The problem is complex and involved, as will be discussed later, but I believe it will yet be solved, and that it will be possible from the records of air temperature in a given locality, by using certain formulæ embracing correlated influences, to determine definitely how nearly the optimum temperature conditions are approached, in terms of percentage. It should at least be possible to discover whether temperature conditions are such as to prohibit the profitable culture of a yet unintroduced crop. If we could

19th Mich. Acad. Sci. Rept., 1917.

apply a formula and find that the peach, for example, in a new region, would come into blossom in the majority of years before the average date of the last killing frost in spring, or if there were not sufficient heat between the time of blossoming and the date of the average fall frost, to ripen the fruit, then it could be positively stated that the growing of peaches should not be undertaken in that region. The Weather Bureau records of temperature in the United States have been collected from so many points and have covered a sufficient length of time to make it possible to define the thermal conditions of small unit areas throughout the country, with great accuracy. What is needed is a statement of the heat requirements of various crops and a method of evaluating temperature records already established, in terms of their efficiency to meet the plant requirements. It will be necessary to consider each crop separately as each has its peculiar characteristics as to minimum, optimum and maximum heat requirements, for its growth and development, and each is able to overcome unfavorable surroundings by acclimatization.

Swingle[1], who has made an admirable study of the climatic requirements of the date palm, has this to say in this connection:

"It is confidently to be expected that in a few years this new branch of biological and economic science which concerns itself with the determination of the exact requirements of crop plants as to climate and soil, and with the finding of the limits of their powers to resist unfavorable influences such as cold, excessive heat, drought, alkali, violent winds, etc., along with a study of the cultural requirements and market conditions of the new industry, will become so well known and its value so well recognized, that it will be a comparatively simple matter to enlist necessary capital and skill in a new culture when once the detailed life history investigations have furnished a sound basis for judgment as to the chances of its proving a financial success in any given region. * * * * * * Millions of dollars have been thrown away in attempts to grow crop plants in regions where a properly carried out life history investigation would have shown there was no hope of success. Unfounded inflation of values of agricultural lands, and the rush into new cultures in unsuitable regions, by whole communities at a time, as the result of a 'boom,' could be largely avoided were it possible to furnish the would-be planter with a black-and-white statement of the necessities of the crop plants under discussion, whereby he would be able to question intelligently whether the region were adapted to the proposed cultures. At present it is no exaggeration to state that the life history requirements and the limits of the power to resist unfavorable environmental conditions are far better known for many microscopic lower plants, such as bacteria, fungi and algae, even for species having no economic importance, than for the most important crop plants whose culture provides employment for tens of millions of human beings, and whose products constitute the daily food of hundreds of millions. Such conditions are discreditable alike to biological and to agricultural science and should no longer continue."

Fortunately the last few years have seen an awakening along this line of investigation, under the leadership of such men as Prof. J. Warren Smith, formerly in charge of the Weather Bureau Office, Columbus, Ohio, and now at the head of the newly established division of "Agricultural Meteorology" at the Central Office of the Weather Bureau at Washington. The establishment of this new division which concerns itself largely with weather and resulting crop conditions, is in itself significant of the fact that the importance of the relationship is being recognized. Prof. Smith[2] has worked out some very practical and interesting relations between weather conditions and crop production, especially in regard to rainfall and corn and potato yields.

Prof. Cleveland Abbe[3] in his "First Report on the Relations Between Climates and Crops," compiled a complete survey of all investigations which had been undertaken up to 1891, along this line, and I must simply refer to that work for a history of the researches which had been made up to that time, in regard to the matter of temperature and plant growth. Suffice it to say that the method used more than any other was one called the summation process. This consisted simply in adding together the daily readings, usually the mean temperature of the day, from the time of planting, for instance, until harvest, thereby establishing what has been called a "thermal constant." It was reasoned that this sum of temperature should be the same year after year, as it represented the amount of heat required by the plant. But it was found not to be a "constant" at all, varying considerably from year to year. The first modification of this process was the introduction of a *plant temperature "zero,"* into the study. This zero was the minimum temperature at which plants would grow, and variously *placed at 32°, 39°, 42°, 50° and even 64° F.* These values were subtracted from the temperature readings before determining the sums for the season. This method presumed that the effectiveness of air temperature in promoting plant growth was directly proportional to the number of degrees above the minimum temperature for plant development. The temperature most frequently used as the zero for plant growth seems to have been 42° F., in which case a mean daily temperature of 50° F. would be given a weight of eight.

Largely to demonstrate the futility of this method which has been used so extensively and is still considered efficient by some, I have taken the splendid phenological records of Mr. Thomas Mikesell[4] and his temperature readings at Wauseon, Ohio, and compiled tables of the sums of temperature readings in the life history of the late Crawford peach, for the years 1883 to 1912, inclusive, shown in Table I. Columns 1 to 5, give, respectively, the temperature summations above 42° F. from

January 1, to blossoming; from blossoming to ripening; from January 1, to ripening; from blossoming one year to blossoming the next, and from date of ripening to the date of blossoming the following spring. It will be noted that there is a wide variation in each column. In the first column, for example, which gives the temperature summations from January 1 to the date of blossoming, the values range all the way from 183 to 362. Sandsten[5] endeavors to account for similar wide variations noted in Wisconsin in studying the problem there, by stating that it is

Table I.

(Mean daily temperature summations in the life phases of the late Crawford peach at Wauseon, Ohio).

(The figures in each column are the total mean temperature readings after subtracting 42 degrees from each daily temperature. Only temperatures above 42° were considered).

| Year. | January 1 to date of first blossom. | Date of first blossom to date fruit ripens. | January 1 to date fruit ripens. | Date of blossoming, previous year, to date of blossoming. | Date fruit ripens, previous year, to date of blossoming. |
|---|---|---|---|---|---|
| 1883 | 356 | 3079 | 3435 | ............ | ............ |
| 1884 | 239 | ............ | ............ | 3565 | 486 |
| 1885 | ............ | ............ | ............ | ............ | ............ |
| 1886 | 307 | 3636 | 3943 | ............ | ............ |
| 1887 | 320 | 3739 | 4059 | 4549 | 913 |
| 1888 | 242 | 3447 | 3689 | 4409 | 660 |
| 1889 | 183 | 3334 | 3517 | 3924 | 477 |
| 1890 | 214 | ............ | ............ | 3978 | 644 |
| 1891 | 228 | 3579 | 3807 | 4331 | ............ |
| 1892 | 309 | ............ | ............ | 4400 | 821 |
| 1893 | 297 | 3663 | 3950 | 4270 | ............ |
| 1894 | 243 | 3906 | 4149 | 4305 | 652 |
| 1895 | 356 | 3991 | 4347 | 4755 | 849 |
| 1896 | 362 | 3650 | 4012 | 4621 | 730 |
| 1897 | ............ | ............ | ............ | ............ | ............ |
| 1898 | 310 | 3543 | 3853 | ............ | ............ |
| 1899 | 339 | 3726 | 4065 | 4793 | 1250 |
| 1900 | 227 | ............ | ............ | 4947 | ............ |
| 1901 | 218 | ............ | ............ | 4927 | ............ |
| 1902 | 270 | ............ | ............ | 4641 | ............ |
| 1903 | ............ | ............ | ............ | ............ | ............ |
| 1904 | 264 | 2948 | 3212 | ............ | ............ |
| 1905 | 274 | 3212 | 3486 | 3824 | 876 |
| 1906 | 294 | 3404 | 3698 | 4295 | 1093 |
| 1907 | 264 | 2766 | 3030 | 4381 | 977 |
| 1908 | 187 | ............ | ............ | 3605 | 839 |
| 1909 | 257 | ............ | ............ | 4434 | ............ |
| 1910 | 232 | 3250 | 3582 | 3929 | ............ |
| 1911 | 236 | 3418 | 3654 | 4258 | 908 |
| 1912 | 322 | 3152 | 3474 | 4588 | 1106 |

## Table II.

(Daily maximum temperature summations during the life phases of the late Crawford peach at Wauseon, Ohio).

(The figures in each column are the total daily maximum temperature readings during the periods shown in the heading, after 42 had been subtracted from each reading. Temperatures above 42° F. only were used).

| Year. | January 1 to date of first blossom. | Date of first blossom to date fruit ripens. | January 1 to date fruit ripens. | Date of first blossom, previous year, to date of first blossom. | Date of ripening, previous year, to date of first blossom. |
|---|---|---|---|---|---|
| 1883 | 979 | 4761 | 5740 | ............ | ............ |
| 1884 | 915 | ............ | ............ | 6608 | 1847 |
| 1885 | ............ | ............ | ............ | ............ | ............ |
| 1886 | 789 | 5796 | 6585 | ............ | ............ |
| 1887 | 957 | 5782 | 6739 | 8033 | 2237 |
| 1888 | 868 | 5454 | 6322 | 7716 | 1934 |
| 1889 | 774 | 5233 | 6007 | 7017 | 1563 |
| 1890 | 683 | ............ | ............ | 7297 | 2064 |
| 1891 | 644 | 5786 | 6430 | 7359 | ............ |
| 1892 | 826 | ............ | ............ | 7727 | 1941 |
| 1893 | 904 | *5661 | *6565 | 7219 | ............ |
| 1894 | 819 | 5220 | 6039 | 7755 | 1916 |
| 1895 | 890 | 6192 | 7082 | 8335 | 2072 |
| 1896 | 744 | 5347 | 6091 | 8008 | 1846 |
| 1897 | ............ | ............ | ............ | ............ | ............ |
| 1898 | 882 | 5223 | 6105 | ............ | ............ |
| 1899 | 794 | 6033 | 6827 | [illegible]69 | 2546 |
| 1900 | 686 | ............ | ............ | [illegible]87 | 2304 |
| 1901 | 727 | ............ | ............ | 8263 | ............ |
| 1902 | 868 | ............ | ............ | 7972 | ............ |
| 1903 | ............ | ............ | ............ | ............ | ............ |
| 1904 | 734 | 5296 | 6030 | ............ | ............ |
| 1905 | 765 | 4982 | 5747 | 6878 | 1585 |
| 1906 | 824 | 5341 | 6165 | 7481 | 2499 |
| 1907 | 733 | 4380 | 5113 | 7517 | 2176 |
| 1908 | 633 | ............ | ............ | 6499 | 2119 |
| 1909 | 765 | ............ | ............ | 7892 | ............ |
| 1910 | 668 | 5314 | 5982 | 7324 | ............ |
| 1911 | 752 | 5198 | 5950 | 7582 | 2268 |
| 1912 | 767 | 4857 | 5624 | 7513 | 2315 |

*Record for six days interpolated.

probably due to the fact that the fruit buds enter the rest period the previous fall under different stages of development, due to unequal heat conditions the previous summer, and suggests that temperature summations, if begun about the time the new fruit buds formed and carried through until they blossomed, would give uniform results. But column 4, which covers practically the time suggested, shows also a wide variation, from 3565 to 4947, a difference too large to be consistent with close

relationships. Neither are the fall temperatures, according to this method, responsible for variations in the amount of heat required in the spring to bring out the fruit buds, as is proven by column 5, which gives the summations of temperature from the date the fruit ripens until blossoming and shows a range of sums from 486 to 1250. Neither do temperature summations from blossoming to ripening or from January 1 to ripening present much closer agreement. Stated in percentage the relation of the lowest value to the highest, in each column, is as follows: Column 1, 50; column 2 and 3, each 70; column 4, 75; column 5, 38. On this basis, of course, if the sums were the same each year, which is the ideal condition, then the percentage would be 100.

It is evident, therefore, that this method of studying the heat requirements of the peach, at least, is not productive of consistent results, and similar studies of other fruits which I have made, but which I shall not take the space to note here, yield similarly unsatisfactory results. Smith[2] has made temperature summations from Mikesell's records for corn, which show as wide variations as those for the peach which have just been discussed. He notes a variation from 1232 to 1919 as the least and greatest temperature summations in the twenty-seven years' records considered, during the period from the time the corn plants appeared above ground until they blossomed, and a variation from 897 to 1607 in the thermal values from the dates of blossoming to ripening. As a result of these studies he comes to the conclusion that, "There is little or no relation between the daily mean temperature and the yield of corn."

The maximum daily temperatures have been considered also as well as the mean temperatures, and Table II, compiled in the same way as Table I, gives the sums of daily maximum temperatures above 42° F., for the peach, the columns corresponding in the two tables. It will be noted that there is a closer agreement between the values given, in each column, in Table II, than in Table I. Stating the relationship between the extremes again in percentage, as was done with Table I, we have in columns 1 to 5, respectively, 64, 71, 72, 78 and 61, or an average of 69 per cent, while the average in Table I was 61 per cent, showing an approach of eight per cent nearer the ideal method in the latter system. A reason for this closer relationship obtained by considering the maximum temperature readings, may be found in the fact that two days may have the same mean temperature, one dark and cool throughout, with no plant growth, and the other colder at night, but warmer in the daytime, with bright sunshine and considerable growth. The latter would have a higher maximum temperature and hence be given a more nearly accurate value in case the highest instead of the mean temperature was considered. This closer relationship between maximum temperature and

plant growth, is brought out in Figure 8, which shows the rate of growth in plants in connection with both the maximum and mean temperatures from May 23 to June 30, 1916, at East Lansing, Mich., which will be discussed further later on.

If the summation methods are to be continued, therefore, I would recommend that maximum temperature readings be considered rather than the means. But neither gives satisfactory results.

As a modification of the summation method of studying the heat requirements of plants, Lehenbauer[6], Livingston[7] and others have used van't Hoff's law in regard to the acceleration of chemical action with increase of heat in evaluating temperature readings. They reasoned that as plant growth is largely chemical in nature, this activity should increase and double with each rise of about 18° F. in temperature, as it does in purely chemical reactions. The formula used is simply $u=2^{\frac{t-42}{18}}$, where $u$ is the value to be derived, and $t$ is the temperature on the Fahrenheit scale. The value derived is therefore the exponential function of the temperature itself, and the method has been termed the exponential method. A temperature of 60° F. would have a value of 2, 78° F., 4, etc.

While this method is an improvement over the summation method, in that it gives increasingly greater weight to higher temperature readings, and therefore probably represents more truly their effectiveness in promoting plant growth, up to a certain limit, yet it does not stop at this optimum for the plant and gives too great values, by far, for very high temperatures. Lehenbauer found, in his measurements of the rate of growth of corn seedlings as influenced by temperature, that van't Hoff's rule applied only to medium temperatures.

This method also fails then, for the same reason, as Zon[8] has pointed out in the case of the summation process, because it does not take account of the fact that there is an optimum temperature for growth in each plant, beyond which the growth rate decreases with further increase in temperature.

Realizing this fact, Livingston[9] has worked out a series of indices of temperature efficiency for plant growth, based on Lehenbauer's measurements of growth of maize seedlings as influenced by temperature. These he terms physiological indices because they are actually based on physiological processes. He has determined a value for each temperature reading on the Fahrenheit and Centigrade scales. In the former he starts with unity at 40° F., increasing to a maximum value of 122.8 at 89° F., and then rapidly decreasing to unity again at 116° F. These values were determined directly from the Lehenbauer growth curve by

measuring the elongation per unit time, using that at 40° F. as unity. Livingston has this to say in regard to this method:

"While it is quite apparent that the system of physiological indices here described is far superior, in several respects, to the other systems heretofore suggested, it is equally clear that these indices are to be regarded as only a first approximation and that much more physiological study will be required before they may be taken as generally applicable. In the first place, they are based upon tests of only a *single* plant species, maize, and there are probably other plants, (perhaps even other varieties of the same species), for which they are not even approximately true. Second, these indices are derived from the growth of *seedlings*, and no doubt other phases of growth in the same plant may exhibit other relations between temperature and shoot elongation. Third, these indices refer to rates of *shoot* elongation, and there are many other processes involved in plant growth, which may require other indices for their proper interpretation in terms of temperature efficiency. Fourth, they apply strictly only under the *moisture, light* and *chemical* conditions that prevailed in Lehenbauer's experiments; with more light or with different moisture or chemical surroundings about the roots, these same plants, in the same seedling stage may exhibit very different values of the temperature efficiency indices. Fifth, and finally, plants in nature are never subject to any *temperature maintained* for any considerable time, and these indices are derived from 12-hour exposures to maintained temperatures. As McDougal[10] has well emphasized, the indices really needed for the ecological and physiological interpretation of temperature must take account of the varying temperatures that are almost always encountered in nature. In the face of these considerations it would be rash indeed to suppose that the index series here brought forward may be found to apply in a wholly satisfactory way to all plants or even plants in general."

In order to test out Livingston's index system, to determine what improvement, if any, is gained over the summation process, I have applied his indices of temperature to the daily mean and maximum temperature readings at Wauseon, Ohio, during the periods in the growth of maize, from the time of the appearance above ground to the time of blossoming, in the years 1895 and 1897. These were the years in which the greatest and least values, respectively, were found by Smith by the summation process. Livingston's indices were also applied to the daily mean and maximum temperature readings during the periods from blossoming to ripening in the years 1906 and 1907, when the highest and lowest values, respectively, were found to have obtained by the summation method. It was believed that if the system of indices brought these extreme thermal values nearer together then it would be an indication that the method was an improvement over the summation system. The results obtained were as follows:

Table III.

Comparison of Indices and Summation System.

| | Year | Summation system (Mean above 43° F) | Livingston's indices system | |
|---|---|---|---|---|
| | | | Mean temperatures | Maximum temperatures |
| Period: Appearance above ground to blossoming time | 1895 | 1919 | 4234.0 | 5962.0 |
| | 1897 | 1232 | 2796.4 | 4373.8 |
| Relation of lower to higher in percentage | ...... | 64 | 66 | 74 |
| Period: Blossoming time to ripening | 1906 | 1607 | 3204.7 | 6029.5 |
| | 1907 | 897 | 1596.2 | 3549.7 |
| Relation of lower to higher in percentage | ...... | 56 | 50 | 59 |

While the Livingston system brought the thermal values for the two years nearer together in the case of the earlier phase of growth, from time of appearance above ground to blossoming, there is even a greater difference in the results obtained for the two years for the period blossoming to ripening when mean temperatures are used, but a slight improvement when maximum temperatures are used. It would seem, therefore, that the indices derived by Livingston from the growth of Lehenbauer's maize seedlings, apply more consistently during the time the plant is passing through the earlier growth phases, but do not hold good for the later blossoming to ripening stage. It may be, as Livingston suggests, that a separate set of indices will be needed for each life phase. The closer results obtained by considering the maximum temperature readings rather than the means, is marked, amounting to eight per cent in the early phase of growth and nine per cent in the later one. This would seem to support my contention that maximum temperatures should be used in these researches, rather than mean temperatures.

It may safely be stated, then, that no way has yet been suggested for interpreting air temperature readings in terms of their efficiency in promoting plant growth, which really satisfies the requirements when put to the test. May it not be that sufficient attention has not been given to the temperature of the plant itself, as it is freely exposed in the air, under more or less sunshine, wind and moisture. The various parts of the living plant have far different powers of absorbing insolation than the air which surrounds them. The color and texture of the surfaces of leaves and stems are such as to make them good absorbers and radiators of heat. Many investigations have shown that leaf temperatures are higher when the sun is shining on them than the air which surrounds them. Ehler[11] has found that the temperature of pine

leaves, even in the winter season, when insolation values are at their lowest, is two to ten degrees C. (3.6 to 18 degrees F.) higher than the air temperature, the latter being in bright sunshine. Askenasy[12], Ursprung[13], Smith[15] and Miss Matthaei[14] have each found the leaves of plants to be warmer than the air, the difference in temperature being dependent upon the clearness of the air, the season of the year and time of day, the wind velocity and possibly other factors. These results have been obtained notwithstanding the fact that so good an authority as Sachs in his Textbook on Botany states that "The leaves and slender stems of plants exposed to the air are generally colder than the air." To be sure, transpiration is a cooling process, and Darwin[16] has found that a difference of 1.5° C. may result between the temperature of two leaves, one freely transpiring and the other not at all. But this process cannot overcome the greater heating effect of the absorption of insolation.

During the past two years some observation has been made of the temperature of leaves of the garden strawberry, *Fragaria vesca,* growing on the Weather Bureau grounds at East Lansing, Mich. (lat. 42° 44 long. 84° 26′ alt. 855 ft.). These observations have been made in a rather crude manner, by means of cylindrical-bulb minimum thermometers, as shown in Plate V. The growing leaf was simply folded around the bulb and held in close contact with it by means of a pin. Care was taken to use a new leaf occasionally, as soon as any signs of retarded growth or wilting became apparent, due to the somewhat unnatural condition of the leaf under observation. It is realized that this method did not give strictly accurate results as to leaf temperature, but the values obtained were sufficiently pronounced to allow for considerable possible error and still show decided differences between the temperature of the plant and that registered by the dry bulb thermometer in the instrument shelter nearby. Readings were made during the greater portion of the growing season thrice daily, 7 a. m., midday, (regularly at 2 p. m. in 1916), and at 7 p. m. The minimum temperature as registered by the minimum thermometer wrapped in the plant leaf, were also noted, with the exception of the months of September and October, 1915, when these readings were omitted. In addition readings were made on a "solar radiation" thermometer, consisting of a blackened bulb instrument, in vacuo, during midday, for the season of 1916. Soil temperature readings, one inch below the surface were also taken daily in 1916, at the same hours as those of plant temperature. The exposure of these thermometers is also shown in Plate V. The additional plant thermometer shown was used only a portion of the season, serving as a check to determine whether slight differences in adjustment of the leaf about the bulb, etc., would cause a difference in the readings. No discrepancies exceeding one degree were noted. The records taken are given in the following tables:

## Table IV—Plant and Soil Temperatures Compared with Shelter Readings.

**For the Month of May, 1915.**

LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.

| Date | Minimum | | | 7 a. m. | | | Mid-day | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil | Plants | Shelter | Soil | Plants | Shelter | Time | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 3 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 6 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 7 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 8 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 10 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 11 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 12 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 13 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 14 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 15 | ...... | 36.0 | 38.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | Cloudy |
| 16 | ...... | 44.2 | 43.9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | Light rain nearly all day |
| 17 | ...... | 38.0 | 37.4 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 42.0 | 45.2 | Cloudy |
| 18 | ...... | 33.0 | 32.9 | ...... | ...... | ...... | 2:00 p. | ...... | 81.0 | 45.0 | ...... | ...... | ...... | Cloudy with showers |
| 19 | ...... | 28.1 | 31.0 | ...... | ...... | ...... | 2:00 p. | ...... | 82.0 | 59.0 | ...... | 47.0 | 53.0 | Clear |
| 20 | ...... | 37.8 | 42.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | Cloudy and rainy |
| 21 | ...... | 40.2 | 48.0 | ...... | ...... | ...... | 2:30 p. | ...... | 76.0 | 73.0 | ...... | 56.0 | 59.0 | Cloudy, rain in morning |
| 22 | ...... | 44.8 | 48.2 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 50.2 | 52.2 | Partly cloudy. |
| 23 | ...... | 36.2 | 39.9 | ...... | 52.5 | 50.0 | ...... | ...... | ...... | ...... | ...... | 60.2 | 63.5 | Clear in morning, partly cloudy p. m. |
| 24 | ...... | 50.0 | 52.1 | ...... | ...... | ...... | 2:30 p. | ...... | 73.0 | 67.0 | ...... | ...... | ...... | Cloudy |
| 25 | ...... | 48.0 | 52.0 | ...... | ...... | ...... | 1:30 p. | ...... | 65.0 | 66.5 | ...... | 59.0 | 60.0 | Nearly clear a. m., cloudy p. m. |
| 26 | ...... | 48.2 | 47.9 | ...... | ...... | ...... | 2:00 p. | ...... | 74.2 | 53.0 | ...... | 39.0 | 41.0 | Mostly cloudy |
| 27 | ...... | 27.4 | 29.9 | ...... | ...... | ...... | 3:30 p. | ...... | 62.0 | 57.8 | ...... | ...... | ...... | Clear a. m., cloudy p. m. |
| 28 | ...... | 37.6 | 41.2 | ...... | ...... | ...... | 2:45 p. | ...... | 60.0 | 62.0 | ...... | 56.2 | 58.0 | Cloudy |
| 29 | ...... | 48.0 | 49.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 49.2 | 52.7 | Cloudy |
| 30 | ...... | 36.2 | 40.8 | ...... | ...... | ...... | 1:20 p. | ...... | 91.7 | 68.0 | ...... | 54.0 | 60.1 | Cloudy early a. m., then clear |
| 31 | ...... | 37.9 | 40.0 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 56.0 | 63.5 | Clear |
| Sum | ...... | 671.6 | 718.7 | ...... | ...... | ...... | ...... | ...... | 664.9 | 551.3 | ...... | 568.8 | 608.2 | |
| Mean | ...... | 39.5 | 42.0 | ...... | ...... | ...... | ...... | ...... | 73.8 | 61.3 | ...... | 51.7 | 55.3 | |

## Table V—Plant and Soil Temperatures Compared with Shelter Readings.

**For the Month of June, 1915.**

**LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.**

| Date | Minimum | | | 7 a. m. | | | Mid-day | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil | Plants | Shelter | Soil | Plants | Shelter | Time | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | 48.3 | 46.0 | ...... | ...... | ...... | 3:30 | ...... | 84.0 | 73.5 | ...... | ...... | 68.1 | Clear a. m., cloudy p. m. |
| 2 | ...... | 52.5 | 55.5 | ...... | ...... | ...... | 4:00 | ...... | 56.0 | 56.0 | ...... | ...... | 55.2 | Cloudy with rain |
| 3 | ...... | 54.9 | 54.9 | ...... | ...... | ...... | 3:30 | ...... | 64.0 | 60.7 | ...... | 58.7 | 60.0 | Cloudy early a. m. then clear |
| 4 | ...... | 53.8 | 54.9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 61.1 | 69.0 | Clear |
| 5 | ...... | 44.0 | 46.1 | ...... | ...... | ...... | 2:30 | ...... | 101.0 | 78.8 | ...... | 60.0 | 69.0 | Clear |
| 6 | ...... | 52.0 | 54.0 | ...... | ...... | ...... | 2:30 | ...... | 95.0 | 83.7 | ...... | 72.0 | 77.7 | Cloudy |
| 7 | ...... | 49.6 | 65.7 | ...... | ...... | ...... | 1:00 | ...... | 73.2 | 75.8 | ...... | 52.0 | 58.5 | Partly cloudy |
| 8 | ...... | 40.1 | 42.9 | ...... | ...... | ...... | 4:30 | ...... | 75.5 | 66.0 | ...... | 57.3 | 61.2 | Partly cloudy |
| 9 | ...... | 44.1 | 47.1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 49.2 | 52.1 | Cloudy, except clear early a. m. |
| 10 | ...... | 37.8 | 38.6 | ...... | ...... | ...... | 2:00 | ...... | 58.0 | 60.0 | ...... | 52.0 | 54.5 | Cloudy, fog early morning |
| 11 | ...... | 52.0 | 54.0 | ...... | ...... | ...... | 2:20 | ...... | 101.0 | 75.0 | ...... | 57.2 | 64.2 | Cloudy a. m., clearing p. m. |
| 12 | ...... | 44.5 | 47.0 | ...... | ...... | ...... | 2:00 | ...... | 88.7 | 78.0 | ...... | 64.0 | 68.1 | Clear a. m., partly cloudy p. m. |
| 13 | ...... | 59.1 | 61.9 | ...... | ...... | ...... | 1:00 | ...... | 91.0 | 82.0 | ...... | 60.2 | 64.0 | Clear early a. m., then cloudy |
| 14 | ...... | 42.8 | 44.0 | ...... | ...... | ...... | 2:00 | ...... | 68.8 | 65.0 | ...... | 58.0 | 59.0 | Clear early a. m., then cloudy |
| 15 | ...... | 54.2 | 53.9 | ...... | ...... | ...... | 4:30 | ...... | 84.0 | 69.0 | 68.0 | 58.8 | 64.0 | Cloudy |
| 16 | ...... | 51.0 | 54.0 | 62.0 | ...... | 64.0 | 3:00 | 69.0 | 64.0 | 64.0 | 64.0 | 59.1 | 69.0 | Clear a. m., cloudy p. m. |
| 17 | ...... | 49.1 | 50.4 | 59.2 | 57.1 | 57.8 | 2:20 | 84.5 | 99.5 | 69.0 | 70.0 | 60.0 | 64.0 | Clear |
| 18 | ...... | 48.0 | 50.0 | 59.9 | 63.0 | 59.9 | 1:30 | 70.0 | 73.0 | 75.5 | 70.0 | 66.0 | 69.0 | Cloudy |
| 19 | ...... | 55.0 | 57.0 | 62.0 | 58.0 | 58.0 | 2:00 | 73.0 | 71.0 | 66.0 | 68.0 | 61.3 | 63.5 | Cloudy |
| 20 | ...... | 55.5 | 55.0 | 62.1 | 65.2 | 59.1 | 1:15 | 84.2 | 95.0 | 69.5 | 71.0 | 62.0 | 66.2 | Partly cloudy |
| 21 | ...... | 48.6 | 50.0 | 60.0 | 66.0 | 61.6 | 2:15 | 71.0 | 68.2 | 69.0 | 67.9 | 61.1 | 64.4 | Partly cloudy |
| 22 | ...... | 52.4 | 55.2 | 61.5 | 60.1 | 60.9 | 1:30 | 80.0 | 94.0 | 71.0 | 67.0 | 57.0 | 62.2 | Partly cloudy |
| 23 | ...... | 38.8 | 40.1 | 52.5 | 55.9 | 49.8 | 2:00 | 86.0 | 97.8 | 64.0 | 69.0 | 57.5 | 60.0 | Clear |
| 24 | ...... | 43.0 | 48.4 | 57.9 | 66.9 | 58.0 | 2:30 | 66.0 | 75.0 | 66.0 | 66.0 | 68.8 | 66.8 | Clear early a. m., then cloudy |
| 25 | ...... | 48.5 | 51.0 | 60.0 | 57.2 | 54.8 | 2:30 | 87.8 | 95.0 | 70.1 | 69.0 | 58.0 | 62.0 | Cloudy a. m., clear p. m. |
| 26 | ...... | 45.0 | 46.0 | 58.1 | 57.8 | 59.4 | 2:30 | 93.0 | 98.5 | 76.8 | 76.0 | 62.0 | 69.1 | Clear |
| 27 | ...... | 49.2 | 51.0 | 62.0 | 67.4 | 64.5 | 1:15 | 95.0 | 103.0 | 79.2 | 78.0 | 64.0 | 71.0 | Clear |
| 28 | ...... | 47.2 | 49.2 | 62.1 | 60.9 | 63.0 | 2:45 | 96.0 | 101.5 | 79.0 | 69.0 | 62.0 | 69.7 | Clear |
| 29 | ...... | 51.7 | 54.9 | 64.0 | 63.1 | 62.0 | 1:20 | 70.3 | 67.0 | 68.9 | 73.0 | 67.0 | 67.1 | Cloudy and rainy |
| 30 | ...... | 53.9 | 54.0 | 63.7 | 63.0 | 58.1 | 4:45 | 82.0 | 79.0 | 79.8 | 76.0 | 68.0 | 68.0 | Dense fog a. m., partly cloudy day |
| 31 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| Sum | ...... | 1461.1 | 1527.7 | 907.0 | 861.6 | 889.9 | ...... | 1207.8 | 2321.7 | 1986.8 | 1121.9 | 1689.3 | 1922.6 | |
| Mean | ...... | 48.7 | 50.9 | 57.1 | 61.5 | 59.3 | ...... | 80.5 | 82.8 | 70.9 | 70.1 | 60.3 | 64.1 | |

## Table VI—Plant and Soil Temperatures Compared with Shelter Readings.

For the Month of July, 1915.

LOCATION:—All readings are taken on the south side of the Weather Bureau building; on the Michigan Agricultural College campus, within a radius of fifteen feet.

| | Minimum | | | 7 a. m. | | | Mid-day | | | | 7 p. m. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Soil | Plants | Shelter | Soil | Plants | Shelter | Time | Soil | Plants | Shelter | Soil | Plants | Shelter | Remarks |
| 1 | ...... | 55.5 | 57.0 | 66.0 | 67.1 | 65.0 | 4:30 | 74.0 | 64.5 | 64.8 | 72.0 | 64.2 | 64.8 | Clear early a. m. then cloudy |
| 2 | ...... | 59.0 | 60.0 | 66.0 | 68.8 | 62.0 | ...... | ...... | ...... | ...... | 78.9 | 66.0 | 69.2 | Partly cloudy |
| 3 | ...... | 49.9 | 52.0 | 62.7 | 71.8 | 60.0 | 12:00 | 76.4 | 83.1 | 71.1 | 70.8 | 60.1 | 66.1 | Clear early a. m. then cloudy |
| 4 | ...... | 50.0 | 51.4 | 62.0 | 64.0 | 62.0 | 12:00 | 68.0 | 68.2 | 70.1 | 64.0 | 58.0 | 57.8 | Cloudy |
| 5 | ...... | 50.0 | 52.1 | 58.0 | 59.0 | 57.0 | ...... | ...... | ...... | ...... | 62.2 | 56.1 | 61.0 | Partly cloudy |
| 6 | ...... | 45.1 | 46.8 | ...... | ...... | 57.9 | 8:45 | 76.0 | 69.7 | 74.4 | 70.0 | 62.1 | 67.0 | Partly cloudy |
| 7 | ...... | 58.0 | 59.9 | 65.2 | 65.0 | 66.2 | 2:30 | 64.3 | 60.9 | 61.0 | 62.0 | 59.9 | 60.0 | Cloudy, rain after 10:30 a m.. |
| 8 | ...... | 57.2 | 58.1 | 62.0 | 60.1 | 60.0 | 1:40 | 88.9 | 80.0 | 73.0 | 70.1 | 62.2 | 68.1 | Partly cloudy |
| 9 | ...... | 49.0 | 48.9 | 60.0 | 64.5 | 62.0 | ...... | ...... | ...... | ...... | 74.0 | 67.0 | 71.0 | Clear a. m., cloudy p. m. |
| 10 | ...... | 55.1 | 56.9 | 64.0 | 65.0 | 68.0 | 12:00 | 88.0 | 91.0 | 79.6 | 74.2 | 67.0 | 71.8 | Clear a. m., cloudy p. m. |
| 11 | ...... | 60.9 | 63.6 | 68.2 | 68.4 | 68.0 | 12:00 | 81.9 | 78.0 | 78.1 | 74.0 | 69.1 | 73.5 | Partly cloudy |
| 12 | ...... | 62.9 | 64.1 | 69.2 | 71.8 | 68.8 | 1:15 | 78.2 | 82.1 | 83.8 | 78.8 | 68.2 | 76.0 | Partly cloudy |
| 13 | ...... | 57.7 | 58.2 | 67.2 | 67.9 | 67.1 | 2:50 | 98.0 | 88.2 | 85.1 | 82.0 | 70.5 | 77.1 | Clear |
| 14 | ...... | 61.1 | 62.0 | 70.8 | 68.2 | 68.5 | 2:20 | 79.2 | 76.1 | 79.0 | 76.0 | 71.8 | 75.0 | Cloudy, but clouds thin |
| 15 | ...... | 67.5 | 68.0 | 71.2 | 69.1 | 70.0 | 6:15 | 75.0 | 78.5 | 76.0 | 75.0 | 73.0 | 75.0 | Cloudy |
| 16 | ...... | 65.8 | 66.0 | 71.0 | 71.0 | 70.2 | 2:30 | 86.0 | 86.0 | 84.0 | 77.0 | 72.3 | 76.3 | Partly cloudy |
| 17 | ...... | 62.0 | 63.0 | 69.0 | 68.7 | 70.0 | ...... | ...... | ...... | ...... | 78.0 | 68.0 | 75.0 | Clear |
| 18 | ...... | 60.8 | 62.1 | 70.0 | 68.8 | 70.2 | 1:20 | 78.0 | 78.0 | 74.0 | 75.0 | 71.0 | 72.7 | Partly cloudy |
| 19 | ...... | 60.9 | 59.1 | 66.0 | 61.0 | 60.0 | 3:00 | 76.0 | 78.8 | 72.5 | 72.0 | 68.0 | 69.0 | Partly cloudy |
| 20 | ...... | 57.2 | 56.9 | 65.8 | 61.9 | 60.0 | 4:30 | 76.0 | 82.0 | 69.5 | 70.0 | 62.2 | 64.1 | Cloudy a. m., clear p. m. |
| 21 | ...... | 50.8 | 50.1 | 62.0 | 58.0 | 58.2 | 2:00 | 78.0 | 80.5 | 64.2 | 68.0 | 59.8 | 61.1 | Partly cloudy. |
| 22 | ...... | 49.0 | 47.8 | 60.0 | 56.0 | 56.3 | 6:00 | 74.5 | 68.0 | 74.0 | 74.0 | 64.0 | 69.0 | Mostly clear |
| 23 | ...... | 50.0 | 50.0 | 63.0 | 58.0 | 61.6 | 1:45 | 88.0 | 90.0 | 78.5 | 74.0 | 64.0 | 70.0 | Clear |
| 24 | ...... | 53.7 | 56.6 | 66.0 | 68.2 | 65.2 | 2:00 | 76.0 | 75.5 | 75.5 | 70.5 | 64.5 | 66.0 | Cloudy |
| 25 | ...... | 60.1 | 59.3 | 66.0 | 65.0 | 68.7 | 2:30 | 79.0 | 83.8 | 78.2 | 72.0 | 65.2 | 66.0 | Cloudy, clouds thin and broken |
| 26 | ...... | 61.2 | 60.6 | 67.0 | 66.2 | 68.0 | 2.45 | 84.0 | 104.2 | 76.8 | 74.0 | 66.0 | 69.0 | Partly cloudy |
| 27 | ...... | 57.8 | 58.0 | 66.0 | 62.0 | 61.0 | 4:45 | 69.0 | 66.0 | 65.0 | 68.0 | 64.1 | 64.7 | Cloudy, rain in p. m. |
| 28 | ...... | 64.0 | 64.0 | 68.1 | 69.0 | 69.0 | 2:45 | 77.8 | 80.2 | 74.9 | 71.0 | 68.0 | 70.0 | Cloudy with showers |
| 29 | ...... | 60.7 | 61.9 | 68.0 | 69.0 | 66.0 | ...... | ...... | ...... | ...... | 72.0 | 72.8 | 72.5 | Cloudy |
| 30 | ...... | 67.4 | 69.0 | 70.3 | 70.0 | 70.0 | ...... | ...... | ...... | ...... | 76.0 | 72.0 | 74.0 | Partly cloudy to cloudy |
| 31 | ...... | 68.0 | 67.9 | 70.0 | 69.0 | 68.0 | 1:30 | 86.0 | 92.0 | 79.0 | 78.0 | 73.0 | 76.5 | Partly cloudy |
| Sum | ...... | 1787.8 | 1811.3 | 1980.2 | 1962.0 | 1994.9 | ...... | 1971.2 | 1979.8 | 1857.1 | 2248.0 | 2049.6 | 2151.5 | |
| Mean | ...... | 57.7 | 58.4 | 66.0 | 65.4 | 64.4 | ...... | 78.8 | 79.2 | 74.3 | 72.5 | 66.1 | 69.4 | |

## Table VII—Plant and Soil Temperatures Compared with Shelter Readings.

**For the Month of August, 1915.**

**LOCATION:**—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.

| Date | Minimum Soil | Minimum Plants | Minimum Shelter | 7 a. m. Soil | 7 a. m. Plants | 7 a. m. Shelter | Mid-day Time | Mid-day Soil | Mid-day Plants | Mid-day Shelter | 7 p. m. Soil | 7 p. m. Plants | 7 p. m. Shelter | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ...... | 64.1 | 64.9 | 70.0 | 68.1 | 70.1 | 2:00 | 90.0 | 95.0 | 85.0 | 80.0 | 75.0 | 78.0 | Clear in a. m., cloudy after 2 p. m. |
| 2 | ...... | 63.8 | 64.8 | 71.0 | 68.1 | 68.0 | 2:30 | 79.0 | 75.0 | 74.0 | 72.0 | 67.2 | 67.0 | Cloudy |
| 3 | ...... | 55.0 | 64.0 | 69.3 | 55.7 | 66.0 | 2:50 | 76.0 | 80.0 | 78.0 | 72.1 | 69.1 | 72.0 | Cloudy |
| 4 | ...... | 60.5 | 60.0 | 66.0 | 61.4 | 60.3 | 2:30 | 71.0 | 79.8 | 68.0 | 60.0 | 61.2 | 61.1 | Cloudy |
| 5 | ...... | 55.9 | 55.0 | 62.0 | 58.1 | 57.0 | 2:20 | 62.1 | 58.2 | 58.0 | 62.0 | 57.9 | 57.1 | Cloudy |
| 6 | ...... | 57.0 | 56.1 | 62.0 | 59.3 | 58.3 | ...... | ...... | ...... | ...... | 66.0 | 61.0 | 63.5 | Cloudy |
| 7 | ...... | 53.3 | 53.8 | 61.9 | 59.1 | 59.0 | ...... | ...... | ...... | ...... | 70.0 | 64.1 | 69.0 | Cloudy |
| 8 | ...... | 56.6 | 57.9 | 64.0 | 62.0 | 63.0 | 12:00 | 89.8 | 88.0 | 78.4 | 76.0 | 70.0 | 71.9 | Clear a. m., partly cloudy in afternoon |
| 9 | ...... | 56.0 | 56.1 | 65.3 | 62.0 | 60.3 | 2:30 | 92.8 | 108.0 | 79.0 | 76.0 | 64.1 | 70.0 | Clear |
| 10 | ...... | 54.0 | 55.2 | 46.0 | 60.0 | 60.8 | 2:20 | 98.4 | 108.0 | 82.2 | 78.0 | 68.5 | 72.0 | Clear |
| 11 | ...... | 57.0 | 58.0 | 67.9 | 63.0 | 62.0 | 2:10 | 70.3 | 70.0 | 71.0 | 70.0 | 66.0 | 67.2 | Cloudy |
| 12 | ...... | 62.0 | 61.0 | 66.0 | 64.0 | 63.0 | 2:30 | 69.5 | 67.5 | 67.0 | 67.0 | 63.0 | 68.8 | Cloudy |
| 13 | ...... | 58.9 | 59.8 | 65.8 | 64.0 | 62.7 | 2:45 | 85.0 | 88.0 | 79.5 | 74.0 | 65.5 | 68.0 | Partly cloudy |
| 14 | ...... | 56.8 | 58.0 | 66.0 | 63.0 | 64.0 | 4:30 | 72.0 | 65.0 | 66.2 | 70.0 | 64.8 | 65.0 | Cloudy |
| 15 | ...... | 57.8 | 58.9 | 65.8 | 62.0 | 63.3 | ...... | ...... | ...... | ...... | 76.0 | 67.5 | 72.1 | Partly cloudy mid-day, clear otherwise |
| 16 | ...... | 60.8 | 62.2 | 64.0 | 66.0 | 67.1 | 1:30 | 84.0 | 93.5 | 82.0 | 72.0 | 66.0 | 65.8 | Clear early a. m., partly cloudy otherwise |
| 17 | ...... | 57.6 | 57.9 | 65.0 | 59.0 | 58.1 | 2:00 | 80.0 | 89.0 | 67.5 | 66.1 | 55.0 | 58.0 | Cloudy until 2 p. m. then clearing |
| 18 | ...... | 42.0 | 42.1 | 56.0 | 47.4 | 49.0 | ...... | ...... | ...... | ...... | 70.0 | 58.8 | 62.7 | Clear |
| 19 | ...... | 46.1 | 47.0 | 58.2 | 51.1 | 53.0 | 4:00 | 79.0 | 90.0 | 75.0 | 70.0 | 59.0 | 63.3 | Clear |
| 20 | ...... | 48.9 | 49.0 | 60.2 | 56.0 | 56.0 | 5:15 | 68.0 | 65.2 | 67.8 | 66.0 | 62.0 | 65.0 | Cloudy |
| 21 | ...... | 59.0 | 60.1 | 65.7 | 62.0 | 63.1 | 3:15 | 67.0 | 64.0 | 63.0 | 66.0 | 62.0 | 68.0 | Cloudy |
| 22 | ...... | 60.2 | 61.1 | 65.0 | 62.0 | 62.2 | 2:30 | 80.0 | 92.0 | 78.5 | 71.0 | 61.5 | 67.0 | Cloudy early a. m., clear rest of day |
| 23 | ...... | 53.1 | 56.0 | 60.8 | 57.8 | 60.4 | 2:45 | 78.0 | 91.0 | 81.0 | 72.0 | 68.0 | 70.7 | Clear a. m., partly cloudy p. m. |
| 24 | ...... | 62.8 | 64.4 | 67.8 | 65.0 | 66.0 | ...... | ...... | ...... | ...... | 67.0 | 60.0 | 61.2 | Cloudy, clouds broken mid-day |
| 25 | ...... | 54.1 | 54.0 | 62.0 | 56.9 | 55.0 | 2:30 | 69.6 | 79.1 | 65.0 | 65.0 | 54.0 | 57.7 | Cloudy, clouds broken mid-day |
| 26 | ...... | 45.8 | 47.1 | 58.0 | 48.0 | 50.1 | 4:00 | 70.0 | 66.0 | 59.7 | 64.0 | 48.8 | 51.2 | Clear |
| 27 | ...... | 37.8 | 38.2 | 58.4 | 42.9 | 45.0 | 2:00 | 86.0 | 92.0 | 67.0 | 66.0 | 51.0 | 55.5 | Clear |
| 28 | ...... | 40.0 | 41.0 | 56.0 | 49.9 | 48.3 | ...... | ...... | ...... | ...... | 66.0 | 55.0 | 58.8 | Partly cloudy a. m., clear after 10 a. m. |
| 29 | ...... | 49.0 | 50.0 | 62.0 | 58.0 | 58.0 | 5:15 | 66.0 | 61.0 | 63.2 | 64.0 | 56.5 | 57.0 | Cloudy, clouds broken |
| 30 | ...... | 40.9 | 43.8 | 56.0 | 46.1 | 46.0 | ...... | ...... | ...... | ...... | 62.0 | 45.2 | 48.2 | Cloudy a. m., clearing noon |
| 31 | ...... | ...... | 40.0 | 53.0 | ...... | 45.0 | 2:15 | 80.0 | 82.0 | 68.0 | 65.0 | 54.5 | 58.2 | Clear |
| Sum | ...... | 1626.9 | 1697.4 | 1952.1 | 1757.9 | 1819.1 | ...... | 1858.5 | 1947.3 | 1724.0 | 2141.2 | 1902.5 | 1980.5 | |
| Mean | ...... | 54.2 | 54.8 | 63.0 | 58.6 | 58.7 | ...... | 74.8 | 77.9 | 65.0 | 69.1 | 61.4 | 63.9 | |

## Table VIII—Plant and Soil Temperatures Compared with Shelter Readings.

**For the Month of September, 1915.**

**LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.**

| Date | Minimum | | | 7 a. m. | | | Mid-day | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil | Plants | Shelter | Soil | Plants | Shelter | Time | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | ...... | ...... | 56.0 | 50.9 | 51.0 | 4:00 | 76.0 | 77.0 | 77.0 | 68.0 | 59.2 | 64.0 | Clear |
| 2 | ...... | ...... | ...... | 58.1 | 53.9 | 58.2 | ...... | ...... | ...... | ...... | 72.0 | 68.5 | 67.0 | Clear |
| 3 | ...... | ...... | ...... | 62.0 | 60.0 | 58.8 | 1:45 | 78.0 | 90.8 | 81.5 | 70.0 | 66.5 | 69.0 | Partly cloudy |
| 4 | ...... | ...... | ...... | 64.0 | 68.0 | 62.0 | 2:30 | 71.0 | 76.0 | 75.0 | 68.0 | 66.0 | 66.1 | Cloudy |
| 5 | ...... | ...... | ...... | 62.2 | 61.0 | 62.2 | ...... | ...... | ...... | ...... | 65.0 | 61.0 | 61.2 | Cloudy with rain |
| 6 | ...... | ...... | ...... | 68.0 | 63.5 | 68.7 | ...... | ...... | ...... | ...... | 64.0 | 61.0 | 62.0 | Cloudy, rain all day |
| 7 | ...... | ...... | ...... | 67.0 | 62.0 | 62.2 | ...... | ...... | ...... | ...... | 70.0 | 66.5 | 69.0 | Partly cloudy to cloudy, rain a. m. |
| 8 | ...... | ...... | ...... | 67.0 | 66.0 | 66.8 | ...... | ...... | ...... | ...... | 78.0 | 71.0 | 75.0 | Cloudy a. m., clear p. m. |
| 9 | ...... | ...... | ...... | 68.0 | 66.0 | 66.2 | ...... | ...... | ...... | ...... | 69.0 | 66.0 | 66.0 | Part cloudy |
| 10 | ...... | ...... | ...... | 58.0 | 56.2 | 54.0 | ...... | ...... | ...... | ...... | 67.0 | 68.5 | 63.9 | Clear a. m., cloudy p. m. |
| 11 | ...... | ...... | ...... | 66.0 | 63.5 | 68.1 | ...... | ...... | ...... | ...... | 68.0 | 64.5 | 65.0 | Cloudy, clouds thin |
| 12 | ...... | ...... | ...... | 64.0 | 64.0 | 64.8 | ...... | ...... | ...... | ...... | 72.0 | 72.0 | 76.0 | Part cloudy |
| 13 | ...... | ...... | ...... | 69.0 | 68.5 | 70.2 | 2:40 | 76.0 | 89.7 | 87.0 | 74.0 | 78.0 | 76.8 | Clear |
| 14 | ...... | ...... | ...... | 71.0 | 72.0 | 74.0 | 2:00 | 80.0 | 92.5 | 89.0 | 76.0 | 77.0 | 79.9 | Clear |
| 15 | ...... | ...... | ...... | 72.0 | 71.7 | 72.0 | 2:00 | 74.0 | 78.5 | 72.0 | 70.0 | 66.0 | 64.7 | Cloudy |
| 16 | ...... | ...... | ...... | 68.2 | 70.9 | 69.0 | ...... | ...... | ...... | ...... | 74.0 | 71.2 | 72.1 | Clear to partly cloudy a. m., cl'dy p. m. |
| 17 | ...... | ...... | ...... | 68.0 | 65.6 | 68.2 | ...... | ...... | ...... | ...... | 71.0 | 68.2 | 65.1 | Cloudy a. m., clear p. m. |
| 18 | ...... | ...... | ...... | 66.0 | 68.5 | 62.2 | ...... | ...... | ...... | ...... | 69.0 | 62.0 | 68.8 | Cloudy to 8 p. m. then clear |
| 19 | ...... | ...... | ...... | 64.0 | 65.0 | 58.0 | ...... | ...... | ...... | ...... | 68.0 | 61.0 | 61.8 | Clear |
| 20 | ...... | ...... | ...... | 62.4 | 61.0 | 61.0 | ...... | ...... | ...... | ...... | 64.0 | 57.0 | 56.0 | Cloudy, clouds broken in a. m. |
| 21 | ...... | ...... | ...... | 55.0 | 57.0 | 46.2 | ...... | ...... | ...... | ...... | 58.0 | 46.0 | 47.2 | Partly cloudy |
| 22 | ...... | ...... | ...... | 50.0 | 51.1 | 39.2 | 2:00 | 66.0 | 70.0 | 66.0 | 58.0 | 48.0 | 49.5 | Clear |
| 23 | ...... | ...... | ...... | 52.0 | 53.0 | 49.1 | ...... | ...... | ...... | ...... | 60.0 | 59.0 | 62.0 | Clear a. m., cloudy p. m. |
| 24 | ...... | ...... | ...... | 60.0 | 59.0 | 58.0 | 1:35 | 72.0 | 86.0 | 72.5 | 64.0 | 57.0 | 59.5 | Partly cloudy |
| 25 | ...... | ...... | ...... | 60.0 | 59.0 | 59.0 | ...... | ...... | ...... | ...... | 66.0 | 64.0 | 67.0 | Partly cloudy |
| 26 | ...... | ...... | ...... | 65.0 | 65.0 | 65.0 | ...... | ...... | ...... | ...... | 58.0 | 51.2 | 51.2 | Cloudy, rain in a. m. |
| 27 | ...... | ...... | ...... | 52.0 | 46.0 | 48.2 | ...... | ...... | ...... | ...... | 54.0 | 47.7 | 48.0 | Cloudy |
| 28 | ...... | ...... | ...... | 48.4 | 41.9 | 39.9 | ...... | ...... | ...... | ...... | 56.0 | 44.0 | 45.8 | Clear |
| 29 | ...... | ...... | ...... | 48.8 | 38.0 | 37.0 | ...... | ...... | ...... | ...... | 57.0 | 47.0 | 49.9 | Clear |
| 30 | ...... | ...... | ...... | 49.5 | 40.0 | 38.0 | ...... | ...... | ...... | ...... | 58.0 | 52.0 | 53.7 | Partly cloudy |
| 31 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| Sum | ...... | ...... | ...... | 1836.6 | 1778.2 | 1730.7 | ...... | 598.0 | 655.0 | 620.0 | 1981.0 | 1827.0 | 1876.7 | |
| Mean | ...... | ...... | ...... | 61.2 | 59.3 | 57.7 | ...... | 74.1 | 81.9 | 77.5 | 66.0 | 60.9 | 62.6 | |

## Table IX—Plant and Soil Temperatures Compared with Shelter Readings.

**For the Month of October, 1915.**

**LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.**

| Date | Minimum | | | 7 a. m. | | | Mid-day | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil | Plants | Shelter | Soil | Plants | Shelter | Time | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | ...... | ...... | 54.0 | 50.0 | 49.0 | ...... | ...... | ...... | ...... | 56.0 | 53.0 | 51.6 | Partly cloudy |
| 2 | ...... | ...... | ...... | 54.0 | 51.2 | 47.9 | ...... | ...... | ...... | ...... | 59.0 | 54.0 | 53.1 | Cloudy a. m., clear p. m. |
| 3 | ...... | ...... | ...... | 56.0 | 54.0 | 53.6 | ...... | ...... | ...... | ...... | 63.0 | 61.0 | 65.2 | Cloudy a. m., clear p. m. |
| 4 | ...... | ...... | ...... | 62.0 | 61.4 | 63.2 | ...... | ...... | ...... | ...... | 59.0 | 54.5 | 54.0 | Clear to part cloudy |
| 5 | ...... | ...... | ...... | 53.0 | 47.5 | 48.8 | ...... | ...... | ...... | ...... | 54.0 | 50.0 | 46.3 | Cloudy |
| 6 | ...... | ...... | ...... | 51.8 | 48.0 | 44.0 | ...... | ...... | ...... | ...... | 51.0 | 45.0 | 43.3 | Cloudy |
| 7 | ...... | ...... | ...... | 50.0 | 45.9 | 46.3 | ...... | ...... | ...... | ...... | 48.0 | 43.0 | 40.0 | Cloudy with rain |
| 8 | ...... | ...... | ...... | 46.0 | 41.9 | 33.1 | ...... | ...... | ...... | ...... | 47.0 | 43.0 | 40.1 | Cloudy with rain |
| 9 | ...... | ...... | ...... | 44.0 | 40.0 | 34.0 | ...... | ...... | ...... | ...... | 46.0 | 42.0 | 37.0 | Cloudy |
| 10 | ...... | ...... | ...... | 40.2 | 33.0 | 31.8 | ...... | ...... | ...... | ...... | 48.0 | 44.7 | 47.2 | Killing frost, clear a. m. |
| 11 | ...... | ...... | ...... | 48.0 | 46.0 | 49.5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 12 | ...... | ...... | ...... | 50.5 | ...... | 49.5 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 13 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 14 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 15 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 16 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 17 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 18 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 19 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 20 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 21 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 22 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 23 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 24 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 25 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 26 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 27 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 28 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 29 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 30 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 31 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| Sum | ...... | ...... | ...... | 609.5 | 518.9 | 550.7 | ...... | ...... | ...... | ...... | 531.0 | 490.2 | 477.8 | |
| Mean | ...... | ...... | ...... | 50.8 | 47.2 | 45.9 | ...... | ...... | ...... | ...... | 53.1 | 49.0 | 47.8 | |

## Table X—Plant, Soil and "Solar Radiation" Temperatures Compared with Shelter Readings.

For the Month of March, 1916.

LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within radius of fifteen feet.

| Date | Minimum | | | 7 a. m. | | | Mid-day (2 p. m.) | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil | Plants | Shelter | Soil | Plants | Shelter | Solar radiation thermometer | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | 10.2 | 11.9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 2 | ...... | a16.8 | 10.9 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| 3 | ...... | a10.0 | 2.0 | ...... | ...... | ...... | ...... | ...... | 38.0 | 22.0 | ...... | ...... | ...... | Clear |
| 4 | ...... | ...... | 5.0 | ...... | ...... | ...... | ...... | ...... | 32.5 | 25.0 | ...... | ...... | ...... | Thin clouds |
| 5 | ...... | 9.2 | 8.0 | ...... | ...... | ...... | ...... | ...... | 51.0 | 28.0 | ...... | ...... | ...... | Thin clouds |
| 6 | ...... | a23.0 | 19.0 | ...... | ...... | ...... | ...... | ...... | a30.6 | 31.2 | ...... | ...... | ...... | Thermometers snow covered |
| 7 | ...... | 25.0 | 28.1 | ...... | ...... | ...... | ...... | ...... | 32.0 | 33.6 | ...... | ...... | ...... | Thermometers snow covered |
| 8 | ...... | a27.0 | 15.8 | ...... | ...... | ...... | ...... | ...... | a34.0 | 18.2 | ...... | ...... | ...... | Thermometers snow covered |
| 9 | ...... | a18.2 | 6.8 | ...... | ...... | ...... | ...... | ...... | a30.0 | 25.0 | ...... | ...... | ...... | Thermometers snow covered |
| 10 | ...... | 25.0 | 14.6 | ...... | ...... | ...... | ...... | ...... | a41.0 | 27.2 | ...... | ...... | ...... | Thermometers snow covered |
| 11 | ...... | a16.0 | 8.1 | ...... | ...... | ...... | ...... | ...... | 49.0 | 34.2 | ...... | ...... | ...... | Clear |
| 12 | ...... | 28.8 | 28.0 | ...... | ...... | ...... | ...... | ...... | 38.0 | 39.0 | ...... | ...... | ...... | Cloudy |
| 13 | ...... | 27.0 | 29.8 | ...... | ...... | ...... | ...... | ...... | 53.1 | 38.1 | ...... | ...... | ...... | Faint sunshine |
| 14 | ...... | 27.0 | 26.0 | ...... | ...... | ...... | ...... | ...... | 27.9 | 22.9 | ...... | ...... | ...... | Snowing |
| 15 | ...... | 15.8 | 12.0 | ...... | ...... | ...... | ...... | ...... | 35.0 | 20.1 | ...... | ...... | ...... | Faint sunshine |
| 16 | ...... | 9.8 | 7.0 | ...... | ...... | ...... | ...... | ...... | 44.6 | 29.2 | ...... | ...... | ...... | Faint sunshine |
| 17 | ...... | 5.0 | 8.1 | ...... | 8.0 | 5.1 | ...... | ...... | 57.0 | 20.8 | ...... | ...... | ...... | Bright sunshine |
| 18 | ...... | 14.0 | 12.1 | ...... | ...... | ...... | ...... | ...... | 34.0 | 29.0 | ...... | ...... | ...... | Cloudy |
| 19 | ...... | 14.0 | 16.1 | ...... | 22.4 | 18.0 | ...... | ...... | 51.3 | 31.0 | ...... | ...... | ...... | Clear |
| 20 | ...... | 17.8 | 16.8 | ...... | ...... | ...... | ...... | ...... | 29.5 | 29.0 | ...... | ...... | ...... | Cloudy, snowing |
| 21 | ...... | a29.0 | 28.9 | ...... | 30.0 | 30.0 | ...... | ...... | a44.0 | 42.0 | ...... | ...... | ...... | Snow covered |
| 22 | ...... | a31.2 | 27.5 | ...... | ...... | ...... | 95.8 | 34.5 | 37.0 | 30.1 | ...... | ...... | ...... | Faint sunshine |
| 23 | ...... | a14.0 | 8.7 | ...... | ...... | ...... | 101.5 | 33.5 | 57.5 | 30.0 | ...... | ...... | ...... | Clear, bright sunshine |
| 24 | ...... | 22.8 | 17.7 | 33.8 | 36.0 | 41.7 | 89.5 | 36.0 | 52.5 | 44.1 | ...... | ...... | ...... | Faint sunshine |
| 25 | ...... | 31.8 | 36.4 | ...... | ...... | ...... | 91.0 | 52.0 | 70.5 | 66.8 | ...... | ...... | ...... | Faint sunshine |
| 26 | ...... | 41.8 | 41.4 | ...... | ...... | ...... | 59.0 | 41.0 | 41.0 | 45.7 | ...... | ...... | ...... | Foggy, dark and cloudy |
| 27 | ...... | 33.7 | 34.8 | ...... | ...... | ...... | 37.2 | 36.0 | 34.1 | 34.2 | ...... | ...... | ...... | Raining |
| 28 | ...... | 32.0 | 32.9 | 34.2 | 32.9 | 33.4 | 46.1 | 40.0 | 41.1 | 37.9 | ...... | ...... | ...... | Cloudy |
| 29 | ...... | 33.0 | 33.9 | 36.0 | 35.0 | 35.0 | 88.5 | 60.4 | 69.0 | 49.0 | ...... | ...... | ...... | Clear |
| 30 | ...... | 31.8 | 31.0 | ...... | ...... | ...... | 92.1 | 64.1 | 72.0 | 58.5 | ...... | ...... | ...... | Faint sunshine |
| 31 | ...... | 28.9 | 28.1 | 35.0 | 32.0 | 31.1 | 91.3 | 54.0 | 57.8 | 58.3 | ...... | ...... | ...... | Cloudy |
| Sum | ...... | 668.6 | 589.5 | 139.0 | b135.9 | b141.2 | 792.0 | 451.5 | 1279.9 | 1000.1 | ...... | ...... | ...... | |
| Mean | ...... | 22.3 | 19.7 | 36.8 | b34.0 | b35.3 | 79.2 | 45.2 | 44.1 | 34.5 | ...... | ...... | ...... | |

a Thermometer bulb and plant snow covered.
b Sums and means for four days only—24, 28, 29, 31.

## Table XI—Plant, Soil and "Solar Radiation" Temperatures Compared with Shelter Readings.

For the Month of April, 1916.

LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.

| Date | Minimum | | | 7 a. m. | | | Mid-day (2 p. m.) | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil | Plants | Shelter | Soil | Plants | Shelter | Solar radiation thermometer | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | 41.1 | 42.8 | 44.0 | 41.1 | 42.8 | 93.8 | 56.0 | 60.0 | 48.9 | ...... | ...... | 43.1 | Partly cloudy |
| 2 | ...... | 24.5 | 27.9 | 34.0 | 33.1 | 32.1 | 95.5 | 63.0 | 75.2 | 51.9 | ...... | ...... | 42.1 | Clear |
| 3 | ...... | 26.0 | 29.0 | 34.1 | 30.0 | 32.2 | 96.5 | 61.0 | 67.0 | 51.7 | ...... | ...... | 43.5 | Very thin clouds. Halo. |
| 4 | ...... | 38.1 | 34.1 | 39.8 | 37.0 | 35.8 | 94.0 | 59.0 | 69.0 | 50.1 | ...... | ...... | 42.9 | Partly cloudy |
| 5 | ...... | 26.8 | 29.1 | 36.0 | 31.1 | 33.1 | 96.0 | 60.0 | 69.0 | 50.7 | ...... | ...... | 40.0 | Partly cloudy afternoon |
| 6 | ...... | 25.2 | 27.0 | ...... | ...... | 28.0 | 89.0 | 55.0 | 46.0 | 40.0 | 40.0 | 29.0 | 33.1 | Snow early morning |
| 7 | ...... | 21.7 | 28.0 | 34.1 | 27.0 | 29.0 | 88.0 | 54.5 | 57.0 | 44.0 | 40.0 | 31.5 | 38.9 | Thin clouds, hail |
| 8 | ...... | 25.3 | 27.0 | 34.2 | 31.0 | 31.5 | 61.0 | 39.7 | 37.1 | 34.0 | 35.0 | 30.5 | 31.8 | Snow flurries after 1:00 p. m. |
| 9 | ...... | 26.9 | 28.5 | 34.0 | 20.0 | 30.0 | 98.0 | 60.0 | 63.0 | 46.2 | 42.0 | 32.0 | 34.8 | Clear |
| 10 | ...... | 25.0 | 24.0 | 34.1 | 28.0 | 31.0 | 97.5 | 62.0 | 63.5 | 53.5 | 45.0 | 38.8 | 44.0 | Clear |
| 11 | ...... | 38.0 | 39.2 | 42.1 | 41.0 | 41.8 | 108.5 | 65.0 | 71.5 | 63.0 | 48.0 | 44.0 | 50.2 | Rain in morning, clear afternoon |
| 12 | ...... | 35.0 | 38.0 | 41.9 | 41.9 | 42.2 | 75.0 | 50.0 | 53.0 | 52.0 | 46.5 | 45.2 | 48.1 | Cloudy, with showers |
| 13 | ...... | 41.0 | 43.1 | 46.0 | 46.1 | 46.9 | 107.8 | 68.0 | 74.0 | 75.0 | 58.0 | 57.0 | 62.0 | Thin upper clouds |
| 14 | ...... | 42.2 | 42.9 | 48.2 | 42.2 | 43.0 | 98.0 | 64.0 | 66.0 | 54.0 | 48.0 | 41.7 | 45.3 | Partly cloudy |
| 15 | ...... | 30.8 | 30.0 | 38.8 | 35.0 | 37.0 | 101.0 | 69.0 | 73.0 | 59.0 | 52.0 | 48.1 | 52.0 | Partly cloudy |
| 16 | ...... | 39.0 | 42.0 | 45.5 | 43.0 | 47.0 | 107.0 | 63.5 | 64.0 | 67.1 | 53.0 | 49.5 | 53.0 | Showers, partly cloudy |
| 17 | ...... | 41.2 | 43.0 | 45.0 | 42.2 | 44.0 | 62.0 | 47.0 | 46.0 | 48.7 | 44.0 | 40.8 | 47.0 | Cloudy, with showers |
| 18 | ...... | 32.1 | 34.9 | 39.4 | 47.9 | 42.0 | 101.8 | 65.0 | 69.0 | 63.8 | 52.0 | 46.0 | 51.8 | Clear |
| 19 | ...... | 41.9 | 42.0 | 46.0 | 48.0 | 44.0 | 87.0 | 50.0 | 47.0 | 48.2 | 48.0 | 45.0 | 48.1 | Light rain during day |
| 20 | ...... | 42.8 | 44.4 | 48.0 | 47.4 | 51.0 | 112.2 | 66.0 | 85.0 | 78.0 | 58.0 | 59.1 | 63.0 | Clear |
| 21 | ...... | 52.1 | 54.7 | 54.5 | 52.2 | 54.7 | 98.0 | 58.0 | 50.0 | 51.1 | 50.0 | 45.5 | 47.0 | Cloudy |
| 22 | ...... | 40.0 | 39.8 | 46.0 | 40.6 | 40.0 | 53.2 | 46.0 | 42.1 | 39.0 | 44.0 | 39.0 | 30.0 | Light rain all day |
| 23 | ...... | 38.0 | 38.0 | 44.0 | 41.0 | 40.2 | 59.5 | 48.0 | 50.5 | 46.7 | 46.0 | 42.5 | 43.6 | Cloudy day |
| 24 | ...... | 38.5 | 39.0 | 44.5 | 41.1 | 41.0 | 81.0 | 52.0 | 57.0 | 50.2 | 50.0 | 45.0 | 45.8 | Thin clouds |
| 25 | ...... | 41.4 | 40.9 | 46.8 | 44.5 | 42.1 | 70.0 | 50.0 | 48.0 | 45.8 | 48.0 | 44.1 | 45.1 | Cloudy |
| 26 | ...... | 40.0 | 41.2 | 46.0 | 44.0 | 44.5 | 67.2 | 50.0 | 50.0 | 50.0 | 48.0 | 44.8 | 46.0 | Rainy |
| 27 | ...... | 38.0 | 40.0 | 46.0 | 43.9 | 42.0 | 108.5 | 65.8 | 69.0 | 60.0 | 56.0 | 48.0 | 51.5 | Clear day, some Cu. Clouds |
| 28 | ...... | 35.8 | 35.1 | 46.0 | 41.8 | 45.0 | 115.0 | 66.0 | 78.0 | 63.0 | 59.0 | 49.5 | 58.0 | Clear and partly cloudy |
| 29 | ...... | 40.7 | 43.1 | 50.0 | 48.1 | 52.0 | 113.0 | 64.0 | 76.0 | 68.7 | 60.0 | 53.0 | 60.0 | Clear |
| 30 | ...... | 46.0 | 50.2 | 53.0 | 52.9 | 54.5 | 108.2 | 62.0 | 65.0 | 65.0 | 56.0 | 49.0 | 49.0 | Mostly cloudy, with showers |
| 31 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| Sun | ...... | 1069.6 | 1113.9 | 1241.0 | 1167.6 | 1220.4 | 2723.2 | 1784.5 | 1840.9 | 1618.8 | 1226.5 | 1098.1 | 1393.4 | |
| Mean | ...... | 35.7 | 38.0 | 42.8 | 40.3 | 40.7 | 90.8 | 57.8 | 61.4 | 54.0 | 49.1 | 48.9 | 46.4 | |

### Table XII—Plant, Soil and "Solar Radiation" Temperatures Compared with Shelter Readings.

For the Month of May, 1916.

LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.

| Date | Total growth of four plants in millimeters | Minimum | | 7 a. m. | | | Mid-day (2 p. m.) | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Plants | Shelter | Soil | Plants | Shelter | Solar radiation thermometer. Maximum | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | 46.8 | 46.5 | 52.2 | 51.1 | 52.7 | 70.0 | 54.0 | 51.0 | 50.9 | 51.0 | 48.5 | 44.2 | Rainy |
| 2 | ...... | 35.0 | 37.0 | 47.7 | 42.0 | 40.5 | 101.0 | 48.0 | 68.0 | 52.0 | 58.0 | 46.0 | 49.0 | Cloudy, clouds thin |
| 3 | ...... | 42.1 | 41.7 | 49.0 | 45.8 | 48.1 | 87.0 | 58.0 | 52.2 | 50.0 | 52.0 | 46.0 | 50.2 | Cloudy, rain during morning |
| 4 | ...... | 36.0 | 37.8 | 46.0 | 48.7 | 46.1 | 104.0 | 62.0 | 78.0 | 62.8 | 56.0 | 58.8 | 57.8 | Partly cloudy |
| 5 | ...... | 46.0 | 50.0 | 51.9 | 51.2 | 55.0 | 115.0 | 70.0 | 84.0 | 71.2 | 60.0 | 48.0 | 57.0 | Partly cloudy |
| 6 | ...... | 44.1 | 48.0 | 54.0 | 50.1 | 54.0 | 92.0 | 60.0 | 67.0 | 65.2 | 60.0 | 56.0 | 68.1 | Rainy until 1:45 p. m., then cloudy |
| 7 | ...... | 45.1 | 49.0 | ...... | ...... | 54.9 | 109.0 | 72.0 | 80.0 | 72.0 | 65.0 | 58.0 | 64.0 | Clear |
| 8 | ...... | 58.0 | 56.0 | 60.0 | 59.2 | 62.2 | 108.0 | 66.0 | 75.0 | 67.0 | 58.0 | 54.0 | 59.8 | Clear |
| 9 | ...... | 37.8 | 40.4 | 50.0 | 42.0 | 46.0 | 107.0 | 68.0 | 78.7 | 68.8 | 61.0 | 51.0 | 57.0 | Clear |
| 10 | ...... | 48.9 | 50.2 | 54.0 | 50.0 | 52.2 | 112.0 | 64.0 | 68.0 | 72.8 | 68.0 | 61.5 | 65.0 | Bright sunshine at intervals only |
| 11 | ...... | 45.0 | 50.1 | 52.0 | 49.0 | 54.0 | 106.0 | 62.0 | 78.0 | 61.0 | 56.0 | 49.0 | 54.0 | Clear |
| 12 | ...... | 35.2 | 36.0 | 50.0 | 40.8 | 45.2 | 98.2 | 62.0 | 62.5 | 59.0 | 56.0 | 50.7 | 58.2 | Cloudy, faint sunshine |
| 13 | ...... | 39.9 | 41.2 | 51.5 | 47.0 | 51.0 | 101.0 | 64.0 | 72.0 | 68.5 | 58.0 | 50.0 | 52.0 | Cloudy, faint sunshine |
| 14 | ...... | 44.0 | 46.0 | 52.0 | 49.0 | 49.5 | 78.7 | 56.0 | 60.0 | 56.1 | 58.0 | 56.5 | 59.0 | Cloudy, showers |
| 15 | ...... | 54.9 | 56.6 | 60.0 | 59.2 | 60.9 | 109.0 | 68.0 | 78.0 | 71.0 | 64.0 | 68.0 | 67.0 | Thin clouds with sunshine |
| 16 | ...... | 45.7 | 50.0 | 56.0 | 52.1 | 58.7 | 104.5 | 62.0 | 66.0 | 56.1 | 52.0 | 45.0 | 46.2 | Partly cloudy, faint sunshine |
| 17 | ...... | 38.8 | 40.6 | 48.1 | 44.0 | 44.0 | 70.0 | 50.0 | 47.0 | 45.5 | 48.0 | 42.0 | 48.2 | Cloudy |
| 18 | ...... | 37.0 | 39.0 | 44.8 | 41.0 | 41.0 | 98.0 | 56.0 | 62.0 | 54.2 | 52.0 | 47.0 | 51.0 | Cloudy, faint sunshine |
| 19 | ...... | 38.0 | 42.0 | 46.7 | 47.0 | 49.0 | 98.0 | 52.0 | 48.0 | 50.0 | 52.0 | 46.9 | 50.0 | Partly cloudy |
| 20 | ...... | 32.2 | 34.6 | 45.0 | 48.0 | 45.2 | 110.0 | 64.0 | 68.0 | 68.0 | 60.0 | 55.0 | 59.0 | Clear a. m., part cloudy p. m. |
| 21 | ...... | 38.8 | 41.9 | 50.0 | 58.0 | 58.2 | 87.2 | 56.0 | 55.0 | 57.0 | 58.0 | 52.0 | 54.2 | Part cloudy to cloudy |
| 22 | ...... | 48.0 | 50.9 | 52.0 | 50.8 | 52.0 | 86.0 | 60.0 | 68.5 | 68.7 | 62.0 | 62.5 | 65.0 | Rainy |
| 23 | ...... | 48.0 | 52.0 | 56.0 | 57.2 | 59.0 | 120.0 | 78.0 | 98.0 | 79.0 | 68.0 | 62.0 | 67.5 | Clear |
| 24 | 61 | 47.0 | 50.0 | 58.0 | 60.0 | 62.0 | 118.0 | 74.0 | 86.0 | 79.8 | 70.0 | 64.8 | 71.0 | Partly cloudy, thin upper clouds |
| 25 | 83 | 56.0 | 58.5 | 64.0 | 62.9 | 66.0 | 120.0 | 79.5 | 92.0 | 81.0 | 72.0 | 68.0 | 71.2 | Clear mid-day, partly cloudy oth'wise |
| 26 | 107 | 54.0 | 56.9 | 62.0 | 61.0 | 62.8 | 118.0 | 80.0 | 87.0 | 79.0 | 72.0 | 69.0 | 71.0 | Mostly clear |
| 27 | 107 | 59.0 | 60.1 | 66.0 | 71.6 | 70.0 | 128.9 | 82.0 | 92.0 | 88.0 | 72.0 | 66.0 | 67.0 | Very thin clouds, sunshine |
| 28 | 110 | 52.2 | 58.9 | 62.4 | 61.0 | 62.0 | 128.5 | 79.0 | 88.0 | 79.0 | 78.0 | 65.0 | 71.2 | Very thin clouds, sunshine |
| 29 | 88 | 54.0 | 57.0 | 68.8 | 60.0 | 61.1 | 98.0 | 67.0 | a85.0 | 64.0 | 65.0 | 60.2 | 61.0 | Cloudy, shower in early p. m. |
| 30 | 73 | 49.5 | 51.2 | 60.0 | 59.0 | 57.0 | 120.0 | 77.0 | 84.5 | 71.0 | 68.0 | 57.0 | 59.8 | Partly cloudy |
| 31 | 62 | 42.0 | 41.0 | 56.5 | 49.4 | 53.0 | 114.0 | 78.0 | 79.0 | 66.0 | 68.0 | 55.0 | 59.5 | Clear |
| Sum | ...... | 1393.5 | 1468.6 | 1621.6 | 1552.6 | 1657.8 | 3192.0 | 2033.5 | 2213.6 | 2008.6 | 1878.0 | 1704.4 | 1822.9 | |
| Mean | ...... | 45.0 | 47.4 | 54.1 | 51.8 | 53.5 | 103.0 | 65.6 | 71.4 | 64.8 | 60.6 | 55.0 | 58.8 | |

a Reading at 12 noon, before shower.

# Table XIII—Plant, Soil and "Solar Radiation" Temperatures Compared with Shelter Readings.

**For the Month of June, 1916.**

**LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.**

| Date | Total growth of four plants in millimeters | Minimum | | 7 a. m. | | | Mid-day (2 p. m.) | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Plants | Shelter | Soil | Plants | Shelter | Solar radiation thermometer. | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | 50 | 42.0 | 48.1 | 56.0 | 58.0 | 58.8 | 89.2 | 72.0 | 71.5 | 72.2 | 65.0 | 68.6 | 66.8 | Partly cloudy |
| 2 | 57 | 57.0 | 59.4 | 68.8 | 67.1 | 68.5 | 111.5 | 75.0 | 85.0 | 74.0 | ...... | ...... | 67.0 | Partly cloudy, sunshine |
| 3 | 48 | 48.8 | 49.1 | 58.2 | 54.0 | 52.2 | 108.0 | 74.0 | 77.2 | 68.0 | 66.0 | 55.5 | 59.5 | Clear |
| 4 | 81 | 46.0 | 48.8 | 59.8 | 58.0 | 59.4 | 98.5 | 71.8 | 78.6 | 71.2 | 66.0 | 60.2 | 65.0 | Partly cloudy |
| 5 | 25 | 46.2 | 48.1 | 60.0 | 58.9 | 57.0 | 100.0 | 75.0 | 84.5 | 70.0 | 68.0 | 59.0 | 68.0 | Partly cloudy |
| 6 | 18 | 47.2 | 49.9 | 58.0 | 54.0 | 54.9 | 84.0 | 68.0 | 69.0 | 67.8 | ...... | ...... | 62.1 | Cloudy |
| 7 | 12 | 49.0 | 51.2 | 58.0 | 56.0 | 57.0 | 58.5 | 58.0 | 54.0 | 55.2 | ...... | ...... | 55.0 | Rainy |
| 8 | 12 | 49.2 | 51.5 | 55.4 | 55.0 | 56.0 | 68.8 | 60.0 | 60.0 | 61.4 | 58.0 | 52.0 | 54.7 | Rainy |
| 9 | 10 | 52.0 | 58.1 | 57.8 | 56.9 | 56.9 | 67.0 | 62.0 | 58.0 | 57.0 | 62.0 | 55.5 | 57.8 | Rainy |
| 10 | 84 | 48.0 | 49.0 | 56.4 | 51.0 | 51.0 | 98.0 | 72.0 | 78.0 | 66.1 | 66.0 | 56.8 | 60.0 | Cloudy a. m., partly cloudy p. m. |
| 11 | 49 | 48.0 | 50.2 | 59.7 | 55.2 | 58.0 | 101.5 | 75.0 | 80.0 | 72.7 | 72.0 | 59.7 | 65.0 | Clear afternoon |
| 12 | 61 | 47.9 | 50.5 | 62.8 | 69.0 | 59.0 | 116.0 | 82.0 | 91.0 | 76.5 | ...... | ...... | 67.1 | Clear to partly cloudy |
| 13 | 78 | 49.8 | 52.5 | 65.0 | 72.2 | 62.0 | 120.1 | 88.0 | 96.1 | 80.5 | 76.0 | 67.0 | 72.0 | Clear |
| 14 | 78 | 56.0 | 60.0 | 68.0 | 67.1 | 67.2 | 77.2 | 69.7 | 67.1 | 66.0 | 66.0 | 60.0 | 68.0 | Rainy at mid-day |
| 15 | 44 | 58.2 | 55.8 | 68.8 | 62.1 | 61.0 | 112.8 | 79.5 | 90.5 | 76.2 | 71.0 | 62.0 | 66.9 | Partly cloudy, bright sunshine |
| 16 | 49 | 58.2 | 55.0 | 65.0 | 67.0 | 59.4 | 80.0 | 71.0 | 67.0 | 67.7 | 66.0 | 60.0 | 62.8 | Mostly cloudy |
| 17 | 84 | 52.5 | 54.0 | 60.0 | 59.0 | 57.1 | 82.0 | 70.0 | 65.5 | 64.0 | 65.0 | 57.1 | 61.5 | Partly cloudy |
| 18 | 28 | 50.0 | 52.0 | 60.0 | 57.0 | 55.0 | 85.0 | 62.0 | 68.6 | 67.0 | 68.0 | 60.0 | 68.0 | Partly cloudy |
| 19 | 24 | 48.0 | 51.0 | 60.5 | 58.1 | 55.0 | 86.0 | 71.8 | 66.8 | 64.1 | 62.0 | 54.5 | 56.0 | Partly cloudy |
| 20 | 16 | 89.0 | 41.4 | 58.0 | 68.9 | 52.0 | 108.0 | 76.0 | 79.0 | 67.2 | 67.0 | 59.5 | 62.0 | Partly cloudy, upper clouds |
| 21 | 16 | 51.2 | 51.0 | 59.0 | 52.1 | 52.0 | 80.0 | 67.0 | 64.0 | 61.8 | 64.0 | 54.0 | 58.0 | Cloudy |
| 22 | 62 | 47.0 | 49.0 | 62.0 | 66.0 | 59.1 | 108.6 | 82.0 | 88.8 | 78.4 | 72.0 | 68.0 | 68.0 | Partly cloudy |
| 23 | 54 | 50.0 | 58.0 | 62.5 | 62.7 | 68.0 | 100.0 | 74.0 | 79.0 | 74.8 | 71.0 | 71.0 | 74.0 | Partly cloudy |
| 24 | 69 | 61.8 | 68.5 | 68.0 | 66.8 | 67.9 | 117.0 | 82.0 | 81.0 | 74.0 | 70.0 | 60.5 | 65.1 | Cloudy a. m., clear afternoon |
| 25 | 70 | 54.8 | 58.0 | 66.0 | 78.1 | 68.0 | 118.0 | 84.0 | 87.0 | 74.0 | 73.0 | 62.0 | 68.0 | Clear |
| 26 | 49 | 49.7 | 58.2 | 64.0 | 67.0 | 64.8 | 99.0 | 79.0 | 80.0 | 79.5 | 70.0 | 62.8 | 64.1 | Increasing cloudiness |
| 27 | 48 | 57.0 | 57.9 | 64.0 | 58.9 | 58.0 | 84.5 | 72.0 | 72.0 | 67.0 | 68.0 | 58.7 | 62.7 | Partly cloudy |
| 28 | 87 | 46.2 | 47.8 | 62.0 | 59.9 | 57.2 | 118.5 | 87.0 | 92.0 | 75.0 | 74.0 | 64.1 | 70.5 | Clear |
| 29 | 82 | 58.0 | 55.6 | 66.0 | 68.1 | 64.8 | 116.0 | 86.0 | 92.5 | 79.2 | 76.0 | 69.5 | 78.0 | Partly cloudy, thin clouds |
| 30 | 55 | 57.5 | 58.0 | 64.0 | 58.0 | 58.5 | 107.0 | 80.0 | 86.0 | 76.0 | 74.0 | 67.0 | 71.6 | Partly cloudy |
| 31 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| Sum | ...... | 1510.2 | 1572.1 | 1842.7 | 1827.1 | 1755.2 | 2880.2 | 2220.8 | 2299.7 | 2099.0 | 1776.0 | 1585.0 | 1924.7 | |
| Mean | ...... | 50.8 | 52.4 | 61.4 | 60.9 | 58.5 | 96.0 | 74.0 | 76.7 | 70.0 | 68.8 | 61.0 | 64.2 | |

## Table XIV—Plant, Soil and "Solar Radiation" Temperatures Compared with Shelter Readings.

**For the Month of July, 1916.**

**LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.**

| Date | Minimum | | | 7 a. m. | | | Mid-day (2 p. m.) | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil | Plants | Shelter | Soil | Plants | Shelter | Solar radiation thermometer | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | 53.0 | 55.0 | 66.0 | 64.8 | 64.0 | 112.5 | 88.2 | 93.3 | 82.1 | 68.5 | 71.0 | 77.0 | Partly cloudy, clouds thin |
| 2 | ...... | 62.9 | 65.0 | 69.8 | 70.0 | 70.8 | 118.8 | 89.0 | 93.0 | 86.8 | 78.0 | 68.0 | 74.0 | Clear |
| 3 | ...... | 55.0 | 57.0 | 68.0 | 63.9 | 61.8 | 119.8 | 89.0 | 97.1 | 79.0 | 76.0 | 65.4 | 72.0 | Clear |
| 4 | ...... | 53.0 | 55.0 | 70.0 | 67.5 | 65.5 | 114.0 | 91.0 | 98.0 | 83.5 | 80.0 | 68.1 | 75.7 | Clear |
| 5 | ...... | 53.8 | 55.8 | 69.0 | 66.0 | 70.0 | 125.0 | 96.0 | 99.0 | 88.5 | 80.0 | 67.5 | 75.8 | Clear |
| 6 | ...... | 55.0 | 56.9 | 70.0 | 67.5 | 69.3 | 128.0 | 95.0 | 104.0 | 86.0 | 82.0 | 70.0 | 77.0 | Clear |
| 7 | ...... | 56.5 | 58.2 | 70.0 | 66.5 | 69.7 | 111.0 | 96.0 | 95.0 | 86.5 | 82.0 | 70.0 | 76.2 | Clear, some Ci. clouds |
| 8 | ...... | 58.8 | 61.0 | 71.0 | 71.0 | 71.2 | 118.5 | 93.0 | 89.0 | 76.0 | 78.0 | 62.0 | 68.3 | Clear, some Ci. clouds |
| 9 | ...... | 50.0 | 52.0 | 64.0 | 61.0 | 60.7 | 100.0 | 87.0 | 88.0 | 76.0 | 78.0 | 66.0 | 71.2 | Partly cloudy |
| 10 | ...... | 49.3 | 51.5 | 64.0 | 61.0 | 61.1 | 125.0 | 94.0 | 106.0 | 84.5 | 82.0 | 68.8 | 74.2 | Clear |
| 11 | ...... | 59.8 | 61.8 | 70.0 | 70.0 | 71.0 | 129.0 | 98.0 | 108.0 | 90.8 | 86.0 | 75.0 | 82.0 | Clear |
| 12 | ...... | 67.0 | 69.0 | 74.0 | 76.0 | 76.6 | 134.0 | 100.0 | 109.0 | 93.5 | 83.0 | 75.0 | 79.2 | Clear until 2 p. m., then cloudy |
| 13 | ...... | 65.0 | 67.1 | 73.0 | 73.0 | 73.0 | 105.0 | 86.0 | 91.0 | 82.6 | 81.0 | 73.2 | 78.0 | Partly cloudy |
| 14 | ...... | 57.0 | 60.1 | 68.0 | 67.0 | 71.0 | 133.0 | 100.0 | 109.0 | 88.2 | 85.0 | 73.0 | 79.0 | Clear |
| 15 | ...... | 61.8 | 63.8 | 72.0 | 70.0 | 71.0 | 97.0 | 92.0 | 85.0 | 85.5 | 86.0 | 78.0 | 85.2 | Part cloudy |
| 16 | ...... | 67.0 | 70.0 | 74.0 | 74.0 | 76.2 | 129.5 | 99.0 | 106.0 | 90.7 | 88.0 | 79.0 | 88.0 | Nearly clear |
| 17 | ...... | 66.0 | 68.0 | 75.0 | 72.0 | 74.0 | 112.0 | 97.0 | 97.0 | 85.5 | 84.0 | 78.8 | 77.8 | Partly cloudy mid-day |
| 18 | ...... | 64.1 | 66.0 | 73.0 | 71.0 | 73.2 | 111.0 | 96.0 | 95.0 | 87.2 | 86.0 | 75.0 | 82.0 | Partly cloudy mid-day |
| 19 | ...... | 65.3 | 68.0 | 74.5 | 72.0 | 75.0 | 131.9 | 96.2 | 112.2 | 93.6 | 88.0 | 75.0 | 84.0 | Clear |
| 20 | ...... | 66.8 | 70.6 | 76.0 | 71.2 | 75.0 | 90.0 | 88.0 | 77.0 | 77.9 | 82.0 | 67.2 | 76.2 | Clear a. m., cloudy p. m. |
| 21 | ...... | 58.6 | 64.8 | 70.5 | 59.6 | 69.0 | 123.0 | 96.0 | 99.9 | 87.1 | 84.2 | 68.0 | 78.2 | Clear |
| 22 | ...... | 56.0 | 61.0 | 70.4 | 64.1 | 69.3 | 126.1 | 96.0 | 102.0 | 91.9 | 85.5 | 68.0 | 74.0 | Clear |
| 23 | ...... | 57.6 | 61.9 | 71.0 | 64.1 | 69.5 | 134.6 | 99.5 | 103.3 | 91.1 | 87.5 | 73.0 | 81.0 | Clear |
| 24 | ...... | 61.0 | 61.0 | 72.0 | 70.0 | 72.1 | 134.9 | 100.0 | 105.0 | 94.2 | 88.0 | 74.0 | 83.0 | Clear |
| 25 | ...... | 62.0 | 64.2 | 71.5 | 69.0 | 73.0 | 134.5 | 100.0 | 101.9 | 94.7 | 88.0 | 74.0 | 88.0 | Clear |
| 26 | ...... | 62.0 | 65.2 | 73.0 | 68.0 | 73.4 | 133.9 | 98.0 | 103.1 | 94.2 | 88.0 | 76.1 | 85.0 | Clear |
| 27 | ...... | 65.0 | 69.0 | 78.0 | 71.5 | 73.0 | 132.9 | 101.0 | 106.1 | 98.0 | 88.0 | 76.0 | 88.0 | Clear |
| 28 | ...... | 66.1 | 69.8 | 76.3 | 72.3 | 75.8 | 125.9 | 99.0 | 96.9 | 96.7 | 89.0 | 80.0 | 85.0 | Partly cloudy |
| 29 | ...... | 67.6 | 72.0 | 76.5 | 73.0 | 76.8 | 132.0 | 101.0 | 107.0 | 101.0 | 90.5 | 67.4 | 88.4 | Clear |
| 30 | ...... | 67.7 | 74.0 | 78.0 | 75.0 | 80.0 | 125.5 | 100.0 | 107.0 | 100.9 | 90.5 | 81.0 | 93.0 | Clear |
| 31 | ...... | 70.8 | 75.0 | 79.0 | 74.8 | 78.0 | 115.5 | 99.0 | 87.8 | 85.0 | 86.0 | 68.8 | 76.0 | Clear |
| Sum | ...... | 1881.0 | 1969.7 | 2227.5 | 2186.8 | 2210.0 | 3753.8 | 2959.9 | 3061.6 | 2733.7 | 2598.7 | 2227.8 | 2446.9 | |
| Mean | ...... | 60.7 | 63.5 | 71.9 | 68.9 | 71.3 | 121.1 | 95.5 | 98.8 | 88.2 | 83.8 | 71.8 | 78.9 | |

## Table XV—Plant, Soil and "Solar Radiation" Temperatures Compared with Shelter Readings.

For the Month of August, 1916.

LOCATION:—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.

| Date | Minimum Soil | Minimum Plants | Minimum Shelter | 7 a. m. Soil | 7 a. m. Plants | 7 a. m. Shelter | Mid-day Solar radiation thermometer | Mid-day Soil | Mid-day Plants | Mid-day Shelter | 7 p. m. Soil | 7 p. m. Plants | 7 p. m. Shelter | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ...... | 55.9 | 59.2 | 70.0 | 60.0 | 63.0 | 118.0 | 96.0 | 92.0 | 81.2 | 80.0 | 61.0 | 69.0 | Clear |
| 2 | ...... | 46.0 | 49.0 | 65.8 | 55.8 | 60.1 | 124.0 | 94.0 | 100.0 | 85.0 | 83.0 | 67.5 | 76.0 | Clear |
| 3 | ...... | 58.0 | 62.5 | 72.0 | 67.0 | 69.5 | 101.0 | 87.0 | 85.5 | 86.3 | 78.0 | 66.0 | 71.2 | Partly cloudy; shower at 1:20 p. m. |
| 4 | ...... | 59.5 | 64.0 | 69.5 | 66.1 | 71.3 | 125.0 | 94.0 | 104.0 | 92.5 | 82.0 | 74.0 | 79.5 | Partly cloudy |
| 5 | ...... | 67.9 | 70.1 | 74.0 | 69.0 | 71.3 | 128.0 | 94.0 | 107.0 | 89.0 | 82.0 | 74.0 | 80.2 | Clear |
| 6 | ...... | 68.5 | 72.2 | 76.0 | 74.0 | 78.0 | 124.0 | 94.0 | 100.0 | 94.3 | 84.0 | 77.0 | 85.8 | Clear |
| 7 | ...... | 70.9 | 75.1 | 76.5 | 75.1 | 79.1 | 98.5 | 92.0 | 84.0 | 89.0 | 82.0 | 76.0 | 82.2 | Partly cloudy with showers |
| 8 | ...... | 67.1 | 70.1 | 74.0 | 70.0 | 71.5 | 128.0 | 88.0 | 97.0 | 83.0 | 78.0 | 66.0 | 74.0 | Partly cloudy |
| 9 | ...... | 55.1 | 59.0 | 68.0 | 61.8 | 64.6 | 118.5 | 86.0 | 96.0 | 82.0 | 76.0 | 63.7 | 70.0 | Clear |
| 10 | ...... | 56.1 | 59.1 | 66.0 | 61.0 | 65.2 | 109.8 | 82.0 | 86.1 | 84.0 | 76.0 | 74.2 | 80.3 | Clear a. m., cloudy p. m. |
| 11 | ...... | 66.8 | 69.1 | 73.5 | 70.2 | 72.8 | 109.0 | 83.0 | 91.0 | 82.0 | 76.0 | 68.5 | 75.0 | Partly cloudy |
| 12 | ...... | 52.2 | 55.0 | 64.5 | 57.4 | 62.0 | 122.0 | 84.0 | 92.0 | 82.0 | 70.0 | 68.5 | 69.2 | Partly cloudy |
| 13 | ...... | 49.0 | 50.9 | 61.5 | 52.0 | 54.9 | 118.5 | 82.0 | 83.0 | 71.8 | 70.0 | 54.0 | 61.1 | Clear |
| 14 | ...... | 43.9 | 44.6 | 58.0 | 49.1 | 53.9 | 88.5 | 74.0 | 73.0 | 71.0 | 68.0 | 57.0 | 62.0 | Mostly cloudy |
| 15 | ...... | 45.0 | 48.3 | 58.5 | 52.6 | 56.0 | 102.0 | 82.0 | 83.0 | 80.0 | 73.0 | 65.0 | 71.0 | Mostly cloudy |
| 16 | ...... | 57.9 | 62.0 | 67.5 | 64.1 | 65.1 | 120.0 | 92.0 | 98.0 | 84.5 | 79.0 | 69.0 | 74.3 | Clear |
| 17 | ...... | 56.8 | 59.8 | 66.5 | 62.0 | 64.0 | 121.0 | 91.0 | 96.0 | 88.2 | 78.0 | 64.0 | 73.3 | Partly cloudy, clouds thin |
| 18 | ...... | 60.0 | 64.7 | 70.0 | 68.1 | 72.3 | 116.0 | 88.0 | 100.0 | 88.0 | 88.0 | 72.0 | 78.0 | Partly cloudy to cloudy |
| 19 | ...... | 67.0 | 70.1 | 72.5 | 72.3 | 75.0 | 120.0 | 98.0 | 103.0 | 95.7 | 84.0 | 75.0 | 84.0 | Clear |
| 20 | ...... | 65.2 | 68.1 | 72.0 | 70.0 | 73.1 | 136.0 | 100.0 | 113.0 | 98.2 | 82.5 | 75.5 | 83.7 | Clear |
| 21 | ...... | 65.0 | 68.1 | 74.0 | 70.9 | 74.0 | 133.5 | 100.0 | 108.0 | 96.2 | 86.0 | 75.5 | 84.0 | Clear |
| 22 | ...... | 68.6 | 73.8 | 76.0 | 72.8 | 76.5 | 129.5 | 96.0 | 104.0 | 87.2 | 80.0 | 64.0 | 69.3 | Clear |
| 23 | ...... | 48.9 | 52.2 | 64.0 | 58.0 | 57.0 | 124.0 | 91.0 | 103.1 | 78.0 | 76.0 | 59.0 | 68.0 | Clear |
| 24 | ...... | 48.9 | 54.1 | 64.0 | 56.0 | 61.0 | 127.8 | 90.5 | 97.8 | 86.0 | 78.0 | 65.5 | 74.0 | Clear until 4:30 p. m., then cloudy |
| 25 | ...... | 48.9 | 52.1 | 62.0 | 58.1 | 57.0 | 94.0 | 86.0 | 85.0 | 78.7 | 78.0 | 69.5 | 66.2 | Clear |
| 26 | ...... | 51.9 | 56.0 | 64.8 | 58.0 | 60.2 | 70.0 | 70.0 | 66.0 | 65.0 | 68.0 | 60.0 | 62.1 | Cloudy |
| 27 | ...... | 43.6 | 46.7 | 58.0 | 48.0 | 51.7 | 108.0 | 72.0 | 86.0 | 71.0 | 68.0 | 54.0 | 60.0 | Partly cloudy to clear |
| 28 | ...... | 38.9 | 41.0 | 56.0 | 45.0 | 48.0 | 118.0 | 74.0 | 103.0 | 75.0 | 70.0 | 55.0 | 62.5 | Partly cloudy to clear |
| 29 | ...... | 46.0 | 49.4 | 59.0 | 53.1 | 57.0 | 110.5 | 77.0 | 92.0 | 89.0 | 72.0 | 59.0 | 65.8 | Clear |
| 30 | ...... | 49.0 | 54.5 | 62.0 | 56.5 | 60.9 | 118.0 | 80.0 | 102.0 | 80.1 | 72.0 | 58.0 | 67.0 | Clear |
| 31 | ...... | 50.0 | 54.1 | 62.0 | 58.1 | 62.0 | 103.0 | 78.0 | 87.8 | 88.0 | 74.0 | 64.5 | 72.1 | Partly cloudy, thin clouds |
| Sum | ...... | 1728.5 | 1834.9 | 2077.6 | 1902.1 | 2007.9 | 3564.1 | 2690.5 | 2918.3 | 2586.9 | 2381.5 | 2046.9 | 2251.8 | |
| Mean | ...... | 55.8 | 59.2 | 67.0 | 61.4 | 64.8 | 115.0 | 86.9 | 94.1 | 83.4 | 76.8 | 66.0 | 72.6 | |

## Table XVI—Plant, Soil and "Solar Radiation" Temperatures Compared with Shelter Readings.

**For the Month of September, 1916.**

**LOCATION:**—All readings are taken on the south side of the Weather Bureau building, on the Michigan Agricultural College campus, within a radius of fifteen feet.

| Date | Minimum | | | 7 a. m. | | | Mid-day (2 p. m.) | | | | 7 p. m. | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Soil | Plants | Shelter | Soil | Plants | Shelter | Solar thermometer | Soil | Plants | Shelter | Soil | Plants | Shelter | |
| 1 | ...... | 59.1 | 68.2 | 68.0 | 64.8 | 65.0 | 83.5 | 72.0 | 71.0 | 69.0 | 70.0 | 62.0 | 66.2 | Cloudy, rain until 1:55 p. m. |
| 2 | ...... | 46.1 | 52.0 | 62.0 | 49.1 | 54.0 | 113.2 | 76.2 | 76.0 | 72.9 | 70.0 | 48.0 | 57.2 | Clear |
| 3 | ...... | 38.0 | 41.0 | 57.0 | 46.0 | 49.0 | 118.9 | 77.0 | 92.0 | 76.0 | 70.5 | 55.2 | 64.0 | Clear |
| 4 | ...... | 51.0 | 56.0 | 62.0 | 60.0 | 61.1 | 86.0 | 74.0 | 77.0 | 76.7 | 70.0 | 55.2 | 70.0 | Cloudy |
| 5 | ...... | 62.0 | 64.1 | 66.7 | 66.0 | 66.3 | 110.5 | 80.0 | 98.0 | 82.0 | 73.0 | 65.0 | 72.0 | Cloudy a. m., clear p. m. |
| 6 | ...... | 59.9 | 68.9 | 68.0 | 67.0 | 67.7 | 130.0 | 87.8 | 101.8 | 87.0 | 78.0 | 67.0 | 74.0 | Cloudy a. m., clear p. m. |
| 7 | ...... | 62.2 | 66.9 | 70.0 | 70.7 | 72.0 | 125.7 | 80.0 | 96.2 | 88.0 | ...... | ...... | 77.1 | Rainy a. m., clearing p. m. |
| 8 | ...... | 58.0 | 60.0 | 66.5 | 61.0 | 61.0 | 119.5 | 80.0 | 108.0 | 78.8 | 72.0 | 55.7 | 68.2 | Cloudy a. m., clear p. m. |
| 9 | ...... | 43.7 | 46.0 | 59.0 | 49.0 | 51.0 | 122.9 | 76.0 | 108.8 | 79.0 | 71.0 | 55.5 | 63.9 | Clear |
| 10 | ...... | 45.9 | 50.0 | 60.0 | 58.8 | 56.0 | 89.0 | 76.0 | 79.0 | 75.2 | 70.0 | 64.5 | 68.7 | Clear a. m., cloudy p. m. |
| 11 | ...... | 58.0 | 62.3 | 65.5 | 63.2 | 65.0 | 103.0 | 82.0 | 88.0 | 84.2 | 74.0 | 64.0 | 71.8 | Clear to part cloudy |
| 12 | ...... | 60.1 | 65.0 | 68.5 | 67.9 | 70.0 | 113.0 | 80.5 | 94.5 | 86.5 | 74.0 | 72.8 | 77.2 | Clear |
| 13 | ...... | 59.0 | 59.3 | 66.0 | 61.0 | 60.1 | 108.3 | 72.0 | 86.2 | 72.9 | 68.0 | 55.0 | 61.0 | Shower in morning, clear later. |
| 14 | ...... | 58.2 | 51.0 | 60.0 | 62.8 | 58.4 | 76.0 | 72.0 | 70.0 | 68.2 | 66.0 | 55.0 | 60.9 | Mostly cloudy |
| 15 | ...... | 41.0 | 45.8 | 57.0 | 49.0 | 50.1 | 67.5 | 65.0 | 58.0 | 55.5 | 58.0 | ...... | 48.0 | Mostly cloudy |
| 16 | ...... | 35.0 | 39.0 | 51.0 | 38.1 | 41.1 | 64.1 | 62.0 | 57.9 | 55.4 | 59.0 | 49.0 | 52.3 | Mostly cloudy |
| 17 | ...... | 48.8 | 48.9 | 55.0 | 49.9 | 49.0 | 91.5 | 68.0 | 78.5 | 60.0 | 60.0 | 48.0 | 48.8 | Clear |
| 18 | ...... | 32.9 | 30.9 | 48.0 | 38.9 | 39.0 | 106.5 | 65.0 | 87.0 | 62.0 | 58.0 | 38.5 | 46.0 | Clear |
| 19 | ...... | 27.1 | 29.9 | 46.0 | 32.9 | 38.0 | 96.5 | 62.0 | 81.0 | 69.0 | 60.0 | 49.0 | 57.5 | Cloudy mid-day. Killing frost |
| 20 | ...... | 41.0 | 46.0 | 51.5 | 48.1 | 52.0 | 118.5 | 70.0 | 89.0 | 78.0 | 66.0 | 64.0 | 68.0 | Clear |
| 21 | ...... | 54.0 | 61.2 | 60.0 | 60.0 | 59.0 | 104.0 | 70.0 | 82.0 | 70.0 | 64.0 | 68.0 | 56.7 | Cloudy, showers |
| 22 | ...... | 44.0 | 48.0 | 52.5 | 53.1 | 55.0 | 69.9 | 62.2 | 64.1 | 60.0 | 58.0 | 50.0 | 53.0 | Mostly cloudy |
| 23 | ...... | 40.2 | 44.1 | 58.0 | 48.1 | 48.0 | 73.0 | 66.0 | 68.0 | 61.3 | 60.0 | 45.0 | 50.7 | Mostly cloudy |
| 24 | ...... | 35.0 | 38.9 | 50.0 | 42.8 | 41.0 | 107.5 | 66.0 | 89.0 | 69.0 | 61.0 | 50.5 | 56.1 | Cloudy early morning, then clear |
| 25 | ...... | 40.5 | 44.1 | 52.5 | 46.2 | 49.0 | 109.0 | 70.0 | 96.5 | 77.0 | 64.0 | 54.0 | 61.2 | Clear |
| 26 | ...... | 52.0 | 58.7 | 58.5 | 58.0 | 55.0 | 82.0 | 68.0 | 74.0 | 74.0 | 65.0 | 64.0 | 67.2 | Cloudy, with showers |
| 27 | ...... | 63.1 | 67.0 | 62.0 | 67.1 | 70.0 | 65.0 | 64.0 | 62.0 | 62.8 | 64.0 | 62.5 | 68.1 | Cloudy, with showers |
| 28 | ...... | 54.0 | 57.0 | 60.0 | 57.0 | 57.1 | 67.0 | 65.0 | 62.0 | 68.2 | 59.0 | 52.0 | 52.0 | Mostly cloudy |
| 29 | ...... | 35.0 | 38.0 | 48.0 | 37.1 | 40.0 | 57.0 | 53.0 | 49.5 | 47.0 | 49.0 | 34.0 | 40.2 | Mostly cloudy |
| 30 | ...... | 27.9 | 30.0 | 41.0 | 31.8 | 38.4 | 105.5 | 60.0 | 80.5 | 62.0 | 52.0 | 42.5 | 48.2 | Clear |
| 31 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | |
| Sum | ...... | 1432.7 | 1527.7 | 1745.2 | 1600.4 | 1635.2 | 2874.0 | 2121.2 | 2415.0 | 2122.1 | 1883.5 | 1585.4 | 1815.7 | |
| Mean | ...... | 47.8 | 50.9 | 58.2 | 58.3 | 54.5 | 95.8 | 70.7 | 80.5 | 70.7 | 64.9 | 54.8 | 60.5 | |

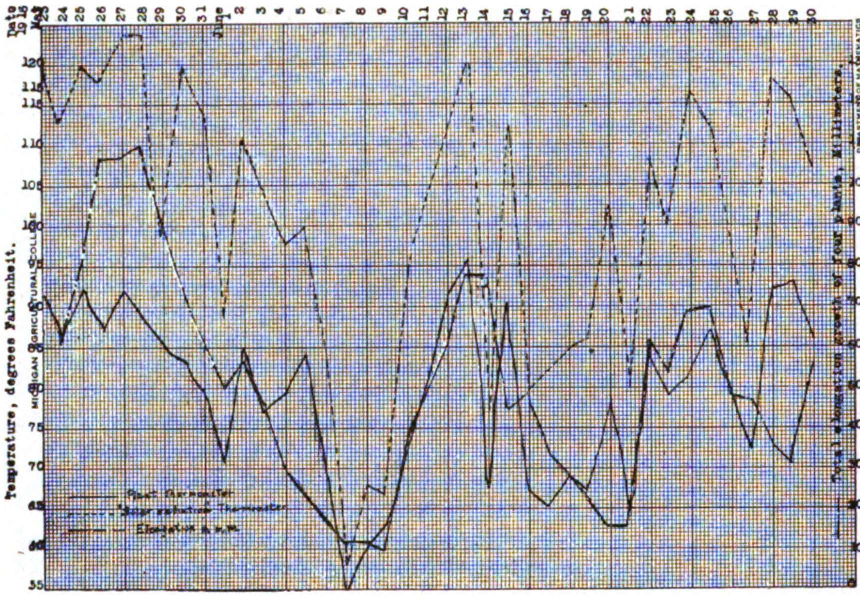

Figure 7. Curves: to show daily readings of the "solar radiation" thermometer (dotted line); plant thermometer readings at mid-day (in solid black); the 24-hour elongation of four plants, in millimeters (dot and dash). Readings were made at 2 p. m. daily.

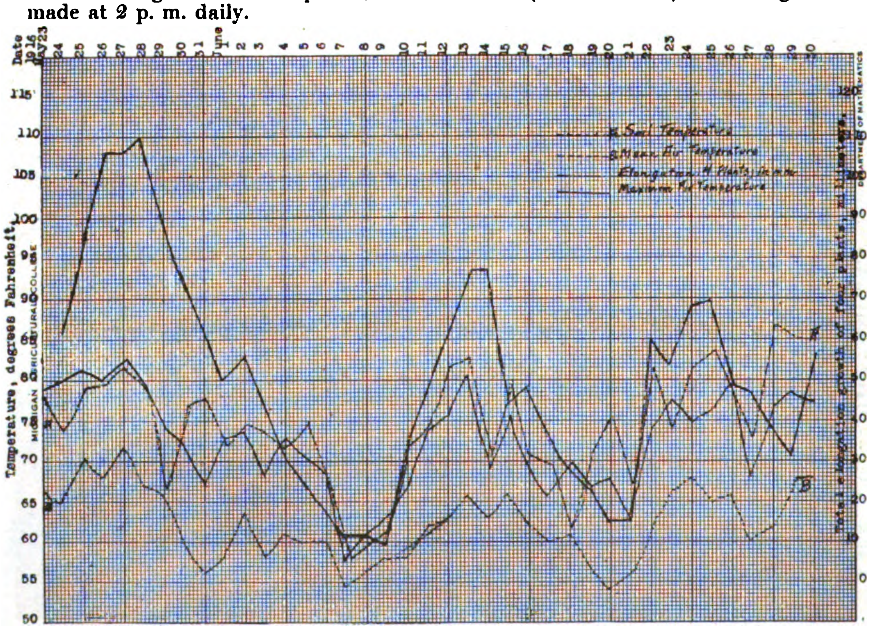

Figure 8. Curves: to show the total growth (elongation) of four plants for the 24-hour periods ending at 2 p. m. daily (dot and dash); the maximum temperature of the air (in solid black); the mean temperature of the air (dotted line, B); and the soil temperature (dotted line, A).

A study of the tables giving the readings of the above thermometers, reveals many interesting facts, only a few of which will be noted here, and those mainly confined to the plant thermometer readings as compared with the recorded air temperatures. In passing I would state, however, that neither the soil nor solar radiation thermometer readings seem to harmonize as closely with plant growth as do the readings obtained in the plant itself. These relationships are shown in connection with curves of growth rates, as reproduced in Figures 7 and 8.

The plant thermometer readings were usually lower than the air temperatures in the early morning, the minimum readings about 3° F. to 4° F. lower than the minimum temperatures recorded in the instrument shelter. Differences were more pronounced, of course, when the weather was clear, and the air still. The plant cooled off more rapidly in the evening than the air which surrounded it, the 7 p. m. readings usually registering 3° to 4° F. lower than the dry bulb thermometer. On very warm days, with clear skies, a difference of 9° to 10° F. was registered at 7 p. m., the plant cooling off much faster than the air. But the most striking difference in temperature occurred during the heat of the day, frequently amounting to 20° F., and on a few days the plant thermometer registered 36° F. higher than the air temperature, at the midday observation. On such dates the air was especially clear and still. On but 41 days out of the 304 on which observations were made at midday, did the plant thermometer register lower than the air thermometer. These were invariably dark and cloudy, many of them with rain falling at the time of observation.

It seems to me that these facts are significant and that plant temperatures should be taken into account to a greater extent in any study of the relation between temperature and plant growth. This may be emphasized by noting the curves reproduced, herewith, in Figures 7 and 8. The curve of plant growth was constructed from observations made of the elongation growth in four plants, two Gladiolus gandavensis, and two Glycine hispida (Soy bean), growing within a few feet of the thermometers used in these observations. The measurements of growth were made by placing a marked leaf against a stake which had been firmly driven into the ground alongside each plant at the start, and marking the height of the leaf tip on the stake each day at 2 p. m. The total daily elongation of the four plants, in millimeters, was used in plotting the curves of growth rate. The plants were kept well watered throughout the experiment. In connection with the growth rate curve in Figure 7, there is also charted a curve of plant temperatures and also one of the solar thermometer readings. It will be noted that the parallelism between the first two mentioned is marked, indicating a close relationship between the

plant temperature and growth rate. Figure 8 shows the same growth rate curve in connection with curves of soil and maximum and mean air Temperature readings, all of which seem to be related, but none as closely as that between the plant temperature and rate of growth.

Another experiment, which gave interesting results, was conducted as follows: On April 6, 1916, before there was any visible sign of awakening in plant life, and no apparent swelling of buds, four small fruit trees, one each of peach, apple, pear and cherry, were dug up from the college nursery and potted in large pots which were placed in the botany department greenhouse. On the nineteenth day of April, thirteen days after removal to the greenhouse, the cherry blossomed, but the others failed to produce blossoms. The first blossom out of doors on the cherry of the same variety came on May 9, thirty-three days after the date of placing the trees in the greenhouse. Temperatures were recorded, both out of doors and in the greenhouse, by means of thermographs, the greenhouse temperature varying but little from 71° F. during the 13 days. From these temperature traces the total number of "temperature-hours" was computed, indoors for the 13 days and out-of-doors for the 33 days, by giving to each hour a value equal to its temperature, minus 42°. This gave for the thermal sum in the greenhouse 9048, and for the open air 4228. Evidently some other temperature than that of the air was active in making up the difference, because, while other factors undoubtedly entered into the problem, the question of heat was without doubt the most vital one concerned. A third temperature trace was constructed by interpolation from the four daily plant temperature readings, (minimum, 7 a. m., 2 p. m. and 7 p. m.), which was, of course, only roughly correct, but which gave a total of 7877 units, by the process mentioned above. The trees in the greenhouse were shaded from the sun and may have been cooler than the bulb of the thermograph nearby, due to transpiration. If we use Darwin's figures, already mentioned, and assume that transpiration reduced the temperature of the trees by 1.5° C., (2.7° F), then we would have for the sum of the thermal values in the greenhouse 8237, as compared with 7877 out-of-doors, so that the results obtained by considering the temperature of the plants themselves agree remarkably closely.

It is a fact that the higher temperature produced by sunshine is only one factor in promoting plant growth, as the actinical effects of sunlight play an important part. The increase in temperature of the plant when bathed in sunshine is probably in proportion to the actinical value of sunlight, so that the temperature readings of the plant in sunshine follow quite closely the resulting growth rate.

With a view to getting a working formula which, although imperfect and subject to amendment after further research, can be used in connection with records of cloudiness and temperature which have been made in any locality, to evaluate such air temperatures as to their efficiency in promoting plant growth, the 304 simultaneous observations of plant and air temperature made at midday in 1915 and 1916, have been studied in connection with the cloudiness, in order to determine factors which can be used to give proper values to temperature readings made on clear, partly cloudy and cloudy days, respectively. The following table gives the number of clear, partly cloudy and cloudy observations, and the sum of the differences between the plant and air temperature readings at midday during the months that observations were made:

Table XVII.

The Effect of Cloudiness on Difference Between Plant and Air Temperatures.

| Month | Clear Weather. | | Partly Cloudy. | | Cloudy. | |
|---|---|---|---|---|---|---|
| | Number of days. | Total temperature difference. | Days. | Total temperature difference. | Days. | Total temperature difference. |
| May, 1915 | 3 | 82.7 | 2 | 27.2 | 4 | 3.7 |
| June, 1915 | 10 | 242.6 | 6 | 71.0 | 12 | 7.0 |
| July, 1915 | 6 | 73.7 | 7 | 50.2 | 10 | -2.0 |
| August, 1915 | 8 | 43.8 | 8 | 67.6 | 8 | 0.2 |
| September, 1915 | 5 | 23.7 | 1 | 8.8 | 2 | 2.5 |
| March, 1916 | 6 | 133.5 | 10 | 124.1 | 13 | 23.5 |
| April, 1916 | 8 | 119.2 | 6 | 61.1 | 16 | 29.2 |
| May, 1916 | 10 | 112.7 | 12 | 88.3 | 9 | 4.5 |
| June, 1916 | 10 | 123.4 | 10 | 72.9 | 10 | 4.0 |
| July, 1916 | 21 | 272.9 | 9 | 56.9 | 1 | -0.9 |
| August, 1916 | 15 | 237.7 | 10 | 88.6 | 6 | -0.3 |
| September, 1916 | 13 | 226.7 | 7 | 57.0 | 10 | 19.2 |
| Total | 115 | 1692.6 | 88 | 773.7 | 101 | 90.8 |
| Average per day | ........ | 15.2 | ........ | 9.7 | ........ | 0.9 |

In round numbers the average difference between the plant and air temperature in full sunshine was 15° F., in partial sunlight, due to thin clouds or intermittent cloudiness, it was 10° F. and less than 1° F. when the sky was thickly overcast, so that the sun's disk was invisible. From these averages we may deduct the following formula for finding the effective temperature from the recorded thermometer readings: $T = t + 15\ C. + 10\ P.$, in which T is the sum of the effective temperature for plant growth, $t$ is equal to $m$—42X, $m$ being the sum of all

maximum temperatures above 42° during the period in question, and $X$ being the number of such days, C is the number of clear days during the period and P is the number of partly cloudy days. In other words, the sum of the maximum temperatures above 42° F. during any period, after 42 has been subtracted from each, is to be increased by 15 for each clear day and 10 for each partly cloudy day during the period. This leaves out of consideration the excess of 1.0° F. in temperature during cloudy weather, which is so small that it may well be disregarded.

The final formula which is to be brought out with further study, will take into consideration more accurate values for plant temperature, and give proper weight to the effect of wind velocity, humidity, and the caloric and actinic value of sunshine. But the above method will be found to be an improvement over the temperature summation methods which has been so largely used, especially if some system such as Livingston's method of indices is used in connection therewith to correlate plant growth and the effective temperatures thus found.

In conclusion I would state that these studies are only preliminary to others which I hope to take up further, with the aid of more accurate instruments and methods. It is realized that an enormous amount of research must be carried through before the final goal of establishing exact formulæ, as to the relationship between climatic conditions and crop production, can be established, and this is only a minute contribution toward the desired end.

I gratefully acknowledge the valuable suggestions and assistance rendered by Dr. E. A. Bessey, Dr. R. P. Hibbard, Prof. C. W. Chapman, and others of the Michigan Agricultural College, and also the aid that Mr. B. B. Whittier, Observer, has given by taking many thermometer readings.

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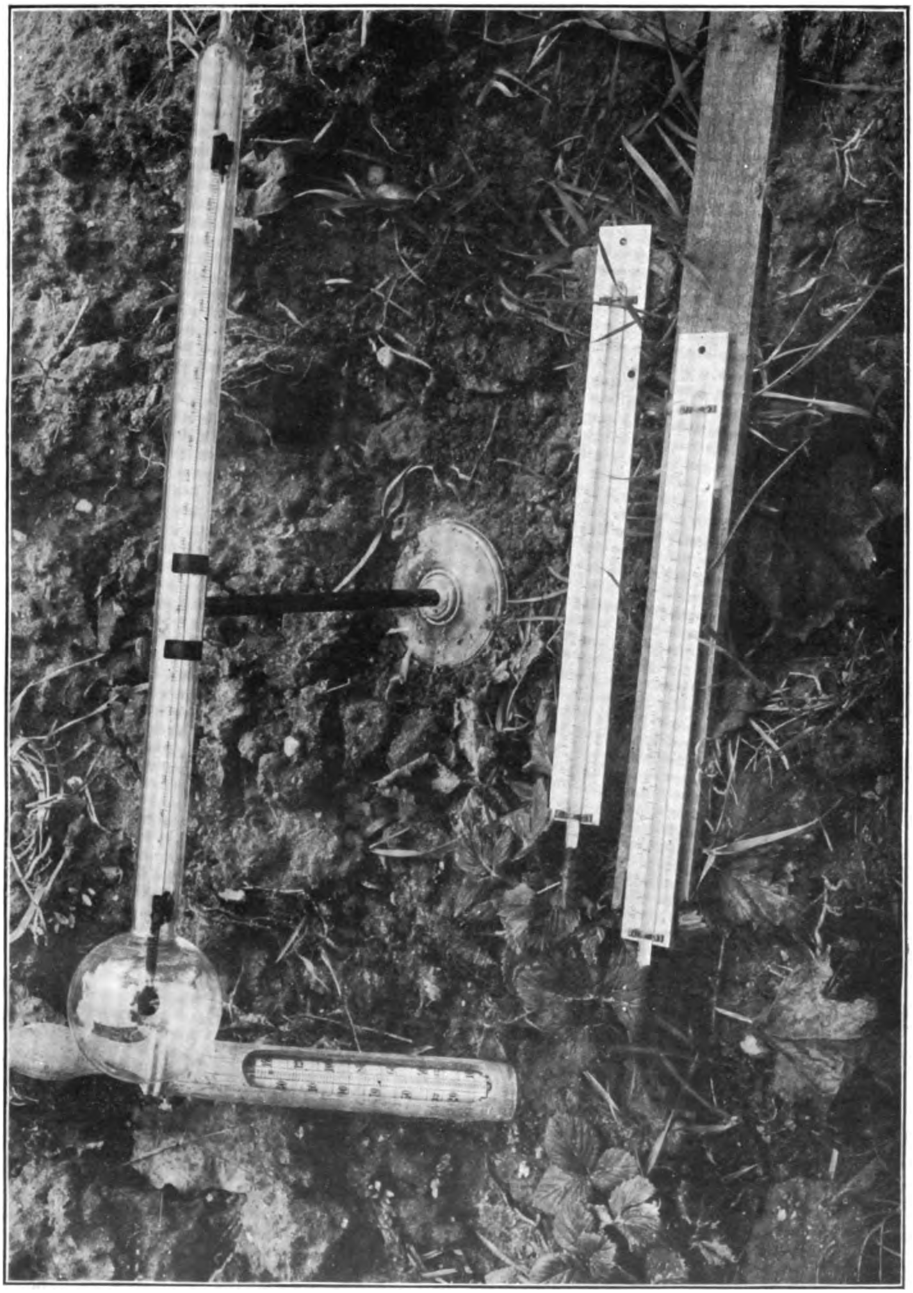
## LEGEND.

Plate V. The exposure of thermometers in the study of plant and soil temperatures at the Weather Bureau Station, East Lansing, Mich.



# ECOLOGY OF NORTHERN MICHIGAN DUNES: CRYSTAL LAKE BAR REGION.

W. G. WATERMAN.

## I. GEOGRAPHY AND GEOLOGY.

A. Geography. (Fig. 9.) Crystal Lake Bar region comprises the territory extending north from Frankfort Harbor, between Crystal Lake and Lake Michigan, past Point Betsie to the mouth of Platte River. On

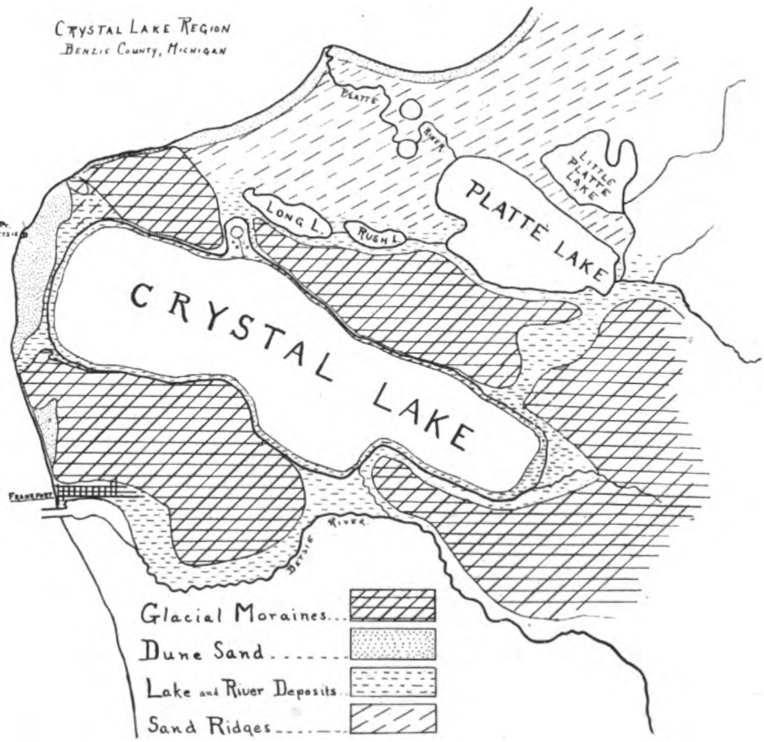



Figure 9. Geography of N. W. corner of Benzie County, Michigan.

the east it contains the western end of Crystal Lake, also Long and Rush Lakes and several small ponds on or near the Platte River. This region is about 10 miles long and extends about one mile inland from

19th Mich. Acad. Sci. Rept., 1917.

Lake Michigan. The only settlements are two summer colonies on Crystal Lake with scattered cottages and farm houses along the state road to the northeast, and a small group of houses around the lighthouse and the coast guard station at Point Betsie.

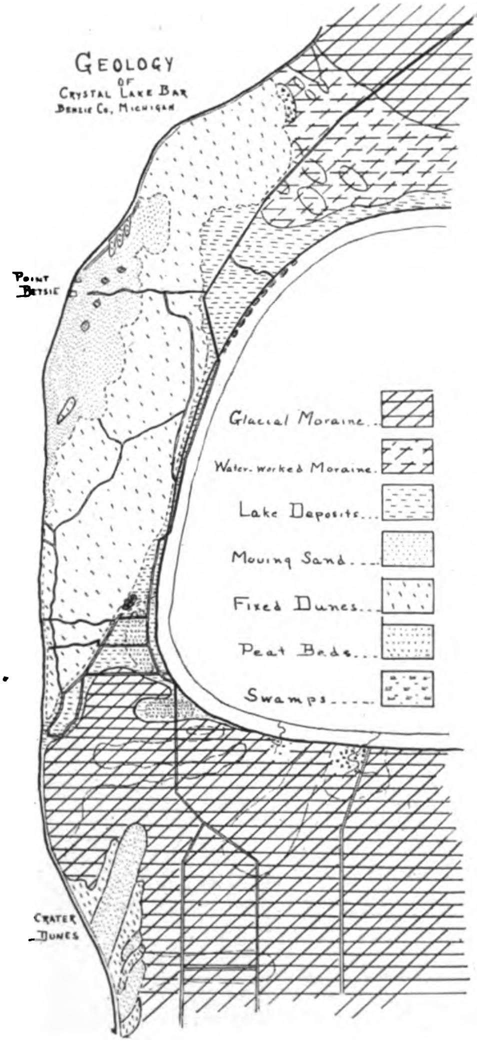



**Figure 10. Geology of Crystal Lake Bar Region.**

B. Geology. (Fig. 10.) 1. Glacial deposits. The dominant features of the relief of the region are two glacial ridges extending from the shore of Lake Michigan to the southeast. They are characterized by gentle slopes and a nearly level sky line, with the exception of two

depressions in the northern ridge, one leading to the west end of Long Lake, and the other to the east end of Platte Lake; and one in the southern ridge, now occupied by the outlet of Crystal Lake to the Betsie River. The edges of these ridges originally extended much farther into Crystal Lake, as indicated by bluffs caused by erosion of the lake. They were also much nearer together at their western ends on Lake Michigan. These ridges are composed mainly of sand and gravel, more or less water-washed and stratified, and they contain at least one layer of laminated clay several feet in thickness, as shown clearly by the exposure on the Lake Michigan bluffs. This layer is marked on these bluffs by a zone of vegetation, which is probably due to the seepage of water held and brought to the surface by this clay layer. The character of the surface soils varies as different layers are exposed by erosion. This glacial deposit was apparently laid down on preglacial ridges, as indicated by the depth of Crystal Lake, which reaches 200 feet in places, and by soundings off shore in Lake Michigan which show the existence of drowned valleys opposite the end of Crystal Lake, and also of Frankfort Harbor. The level areas between the ridges are due to water action at the time of the Algonquin depression.

The topography as well as the character of these deposits and the identification of Algonquin beaches, show that in Algonquin times Crystal Lake was connected with Lake Michigan toward the north by channels passing west of Long Lake, toward the south through the valley of the present outlet, and to the west through the then unfilled valley which now contains Crystal Lake. During this time a broad harbor bar was built across this valley between the western ends of the glacial ridges. This bar, which is approximately two miles long and three-quarters of a mile wide, now cuts off Crystal Lake from Lake Michigan, and accounts for the name given to this region. At present the western outline of the bar is convex, but probably when first formed the glacial ridges extended much farther into Lake Michigan, and as they have been cut back the bar assumed its present shape. The region is still being eroded, as shown by the sand and clay bluffs and by the presence of fixed dunes, the western ends of which have been entirely eroded away by lake action.

2. Nipissing formations. Beyond Point Betsie extending to the northeast from the western end of the northern glacial ridge is an expanse of sand ridges of slight elevation with depressions between. This formation extends six miles to Platte River, and beyond that toward Empire, and is about one mile in width. It apparently dates from Nipissing times, and is very similar to the characteristic formation of similar origin at the head of Lake Michigan in Indiana and Illinois. As

this formation will not be referred to again, a description of its vegetation will be given at this point.

The sand ridges have a characteristic cover of Quercus rubra, Quercus velutina, Pinus Banksiana, Pinus Strobus, Pinus resinosa, with Vaccinium, Gaylussacia, Epigaea, and Gaultheria undergrowth. The depressions show all phases of hydrarch successions, from Nymphaea up, including sphagnum bogs with Sarracenia and Betula pumila, and Chamaedaphne meadows with Vaccinium corymbosum and similar forms. Along the Michigan shore runs a narrow belt of low shore dunes, more or less rejuvenated. In appearance and vegetation they are similar to those around Point Betsie, to be described later.

Another relic of Nipissing times is an elevated beach just north of the lighthouse at Point Betsie. (Plate VI, Fig. 1.) The reason for its preservation is probably its proximity to glacial gravels which formed a protecting layer of shingle so that now the beach looks very much like a railway embankment, preserving its original sloping front toward the water, with a similar slope on the opposite side, caused by the wind blowing out the sand from among the pebbles.

3. Dune formation. Soon after the recession of post-glacial lakes the wind began its work of piling up dunes. Apparently they were at first located much farther west, on land since eroded by the lake. They have been continually in motion, passing through the usual cycles of fixation and rejuvenescence. They are found in two main localities in this region. A large complex on the Crystal Lake Bar surrounding the present Point Betsie, and a small group of perched dunes, called locally from their chief spectacular feature, the "crater" group.

a. Point Betsie Complex. (Plate VII.) This group is located on Crystal Lake Bar, starting in a point on Lake Michigan at the western end of the grounds of the Congregational Summer Assembly, and spreading like a fan toward the north, and is about two miles in length and half a mile in width at its widest point. Its elevation varies from the water level to ridges upwards of 200 feet in height. At the southern extremity of the group the dunes are fixed, and extend from bluffs on the eroding shore to a steep lee slope on the eastern side. The contour is very uneven, showing dune ridges and outlines of blowouts. These are covered by a climax forest and have evidently been untouched for a very long time. Approaching Point Betsie the shore cliffs gradually become lower, and give place to a complex of moving sand. Great troughs lead from the shore for half a mile or more inward, to the advancing lobes of the lee front. Among these blowouts are found residual patches of the original forests. Just north of Point Betsie is a rather large patch of relic forest on three dune ridges, which extend

southeastward from sand bluffs on the lake. On either side of them the sand has been blown out by both southwesterly and northwesterly winds, and a semicircular trough with a very large horseshoe front has been formed. This is one of the largest blowouts in the whole dune region of Lake Michigan, and is unique in this locality at least in showing the influence of winds from two directions. Beyond this blowout the dunes are higher and the steep sand cliffs begin again, and finally end about a mile north of Point Betsie with a definite lee slope just where the edges of the moraine ridge grade into the level surface of the bar. Under these dunes the moraine apparently extends some distance to the south as glacial pebbles have been found *in situ* almost to the top of the bluffs on Lake Michigan to a point within a quarter of a mile of the lighthouse.

b. The Crater Group. (Plate VI, Fig. 2.) This second group of dunes is found half a mile north of Frankfort on the shore, forming a most interesting group of detached, perched dunes. They are only half a mile in length and one-quarter of a mile in width, and extend almost north from the shore, which at this point lies northwest and southeast. The group consists of small fixed dunes which evidently once extended much farther out into the lake. They are from 50 to 100 feet in height, but are placed on a morainic plateau, which itself rises 100 feet above the lake. These fixed dunes have been blown out through the center in a long trough, which is itself complex and shows traces of a number of parallel blowouts. These all end in a large steep-sided, semicircular blowout, popularly called the "crater."

## II. CHARACTER OF ENVIRONMENTAL FACTORS.

A. Climatological. So far it has been possible to obtain only incomplete and not entirely satisfactory observations, so that only a brief general statement will be given. There is nothing exceptional about the meteorological conditions of this region as to precipitation and moisture in the air and in the soil. On account of the marked projection of Point Betsie into Lake Michigan, it is exposed both to southwesterly and northwesterly winds, which probably accounts for the large amount of moving sand around the Point, as well as for the large blowout described above. The wind also has an indirect influence on evaporation and temperature, especially in the summer, as a marked difference in both is observed when a period of easterly winds is followed by a similar period of westerly winds.

B. Substratum. On the dunes the blown sand is generally homogeneous in physical character, but a marked characteristic is the large percentage of calcium carbonate present in the form of residual grains formed by the grinding up of shells, apparently chiefly of Gastropods.

This calcium carbonate content varies from one to five per cent. The dune sand is also characterized by a very unequal distribution of organic material, in the presence not only of old soil lines, but also of individual plant parts and of patches of dark material, apparently carbonaceous, with rare ferruginous patches, and also marly layers, indicating apparently the location of former pannes. The surface of the glacial deposits is mainly outwash, consisting of sand with more or less gravel, and even boulders, and with occasional exposures of clay layers.

The moisture content of the soil varies with the location and with the character of the substratum as shown in the following table:

Table I.

Relation of Character of Substratum to Moisture Content.

| Locality. | Depth in cms. | Wilting Coeff. | Average moisture content 8 weeks, July and Aug., 1916. |
|---|---|---|---|
| Open Dune Summit ............. | 7 | .5 | 2. |
| Open Dune Summit ............. | 25 | .5 | 2.5 |
| Forested Dune Summit ......... | 7 | 1.8 | 2.1 |
| Forested Dune Summit ......... | 25 | .3 | 1.3 |
| Forested Dune Side ............ | 7 | 1. | 2.2 |
| Forested Dune Side ............ | 25 | .3 | 1.2 |
| Glacial Moraine ................ | 7 | 3.3 | 7.5 |
| Glacial Moraine ................ | 25 | 2.4 | 5. |

## III. ECOLOGY.

(Fig. 11.)

A. Climax forest. The whole region, including at least part of the moving area, was originally covered by a heavy climax forest, (Plate VIII), which is still practically untouched in the southern tip and along most of the eastern edge of the dunes. The level ground on the Bar has largely been cleared, and is covered with second growth of forest trees and clearing pioneers, where not occupied by summer cottages. The climax forest is composed of beech, maple, and hemlock, with much yellow birch. The trees are tall and slender with close stand and very little undergrowth, where undisturbed. Occasional specimens of Quercus rubra, Pinus Strobus, and Pinus resinosa are found. Among the shrubs, Acer spicatum, about at the southern limit of its range, Viburnum acerifolium and Taxus canadensis are conspicuous. Characteristic species in the undergrowth are Aralia nudicaulis, Streptopus roseus, Clintonia borealis, Aralia racemosa, Maianthemum, Linnaea borealis and Mitchella repens, with Aspidium spinulosum, Adiantum pedatum, and Botrychium virginianum.

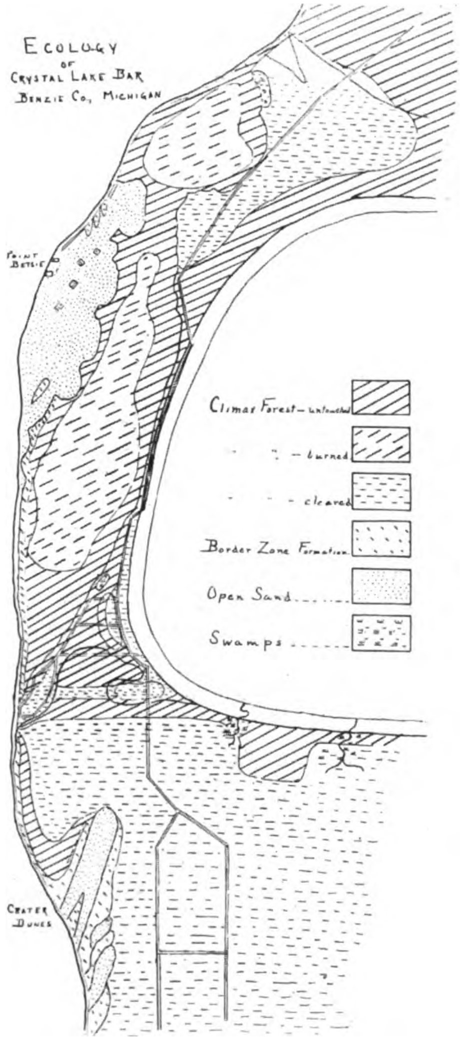



**Figure 11. Ecology of Crystal Lake Bar Region.**

Burned Area. The northern and central portion of the forested strip has been burned, in some parts repeatedly, in others not so recently. In the much burned portions the tree specimens are young and somewhat stunted. In the other portions the trees are larger and the undergrowth thicker. The species include Betula alba, Prunus virginiana, and Prunus pennsylvanica, with the more xerophytic relics of the mesophytic undergrowth, and much Pteris and Equisetum.

Border Zone Formation. Where the climax forest, still untouched, extends to the shore, a zone 50 to 100 yards in width, shows a very characteristic difference in species. (Plate IX.) The trees are Thuja, Ostrya, Tilia, and Abies balsamea, with Celastrus scandens. The line of demarcation is not sharp, but the climax trees, especially hemlock, mingle with the others almost to the edge of the cliffs. The characteristic border zone species are not found farther back in the climax forest.

B. Dune Complex Vegetation. On the open dune complex there are found a number of forest patches, apparently growing in valleys between former fixed dunes whose summits have been entirely blown away. (Plate X.) The interiors of these patches present all the characteristics of a heavy forest, and their evaporation rate is almost as low as that of the climax forest. But the vegetation is characteristic of the border zone described above, containing especially Thuja and Abies, and is marked by some trees reaching two feet in diameter, but not over 80 feet in height. The undergrowth is similar to that of the climax forest, but is especially characterized by Viburnum acerifolium, Rhus toxicodendron, and Aralia nudicaulis. On the edges, next to the open sand, are found Arctostaphylos, Linnaea and Juniperus horizontalis. These apparently originate in the fixed area, and extend out on to the sand, forming a protective covering, which frequently contains also Juniperus communis. Buried trees and occasional graveyards are to be found all over the moving sand area.

There is not much forest reproduction on the moving sand, and, unlike some similar regions, no young stands of Pinus Banksiana, nor any cottonwood dunes similar to those of the Indiana-Michigan region. There are practically no panne colonies, but a few isolated oval groups, chiefly of Thuja and Betula alba, which seem to have originated from pannes, growing upward as the sand accumulates around their stems. A few other patches have reached the low conifer stage, but seem to have been chiefly invasions from the relic patches previously described. On the open sand the vegetation consists of characteristic pioneer herbs, Ammophila and Calamovilfa among grasses, with Lathyrus maritima, Artemisia, Campanula rotundifolia, Cirsium Pitcheri, some Hudsonia, and Zygadenus chloranthus. There are frequent mounds protected by Calamovilfa, Prunus pumila, Salix syrticola, and Cornus stolonifera.

The growth of grasses, especially Ammophila, is quite extensive, and frequently approaches the character of fixed grass dunes. This is especially noticeable on the advancing lee slopes, where the complex is overwhelming the climax forest.

C. Vegetation of the Crater Group. This group apparently consisted at first of fixed dunes which were at least partly covered by the

climax forest of the glacial plateau on which they are perched. At present the outer slopes of the fixed dunes, from which the center has been blown out to form the trough, are covered by a formation similar to the border zone and relic patches already described. On the open sand of the trough are found the usual pioneers of the region, with in addition a great abundance of Anemone multifida and Lilium philadelphicum. The sides of the earlier troughs are frequently covered with Ammophila and Calamovilfa, and in places practically form fixed grass dunes.

D. Crystal Lake Beach. The west end of Crystal Lake is bordered by a sandy beach 400 feet in width, with a slight slope toward the water. The history and ecology of this beach are very interesting. At the beginning of historic times the waters of Crystal Lake were approximately 15 feet above their present level, being impounded by a sand bar across the mouth of the present outlet. The waters of the lake apparently escaped by seepage through the sand. About 1871 certain individuals formed the ambitious plan for an inland waterway from Frankfort Harbor, through the Betsie River, Crystal Lake, Long and Platte Lakes, and began operations by cutting through the sand bar on Crystal Lake. This of course lowered the water of the lake rapidly, and laid bare this under-water shelf or sand terrace. Nothing further was done with the inland waterway scheme, and the beach has remained exposed to the present. As a result of this exposure of a broad sand area, the formation of dunes began at the first point on the west end of the lake where the southwest winds could get sufficient sweep. These dunes extend for nearly a mile, and increase in size toward the north. At the beginning they are almost indistinguishable from the beach, and at the other end have reached a height of 10 or 15 feet and a length of 50 feet. The vegetation on these dunes is scattered and consists chiefly of Ammophila. The vegetation of the beach is interesting because a definite date can be set for its beginning. At present it consists chiefly of Juncus balticus in the wetter portions, some species of Aster, Solidago, and stunted shrubby growths of Salix, Populus balsamifera, and Betula alba. At certain points there has been a slight invasion of Thuja, apparently from swamps of the high water period. At one point on the beach there can be seen four stumps of trees which apparently grew on the beach at a prehistoric period of low water similar to the present although they may have floated there from the shore at the high water stage. These stumps are about three feet in diameter, and have been identified as Pinus Strobus. They were cut off level by the action of the beach gravel, and the sand has been lowered around them by wind action approximately eight inches. Their presence is interesting as

indicating a possible former vegetated period for the beach if they should prove to be indigenous, and in either case they give a measure for the reduction of level of the beach by removal of sand by the wind.

### IV. PROBLEMS.

It seems desirable to indicate here certain problems which suggest themselves in connection with the study of this region. At present possible lines of solution can only be hinted at but study of their phenomena will be continued, for their solution would throw much light on some obscure points in the principles of dune succession.

A. Character and Cause of the Border Zone Formation. It will be noted that this formation is found only on the edge of the climax forest bordering on the bluffs on Lake Michigan and in relic patches on the Point Betsie complex. The species involved are more xerophytic than those of the climax forest. Two factors suggest themselves as chiefly contributing to produce this marked difference in vegetation. One is that of light, for Thuja and Abies balsamea apparently are not shade tolerant, and do not grow to any size when they accidentally germinate in the heart of the climax forest. The other would be the moisture situation, but so far as atmospheric conditions are concerned, atmometer readings show that certain hill tops of the fixed dunes covered by a climax forest have a higher evaporation ratio than this border zone, but they are covered by the characteristic climax formation, except that relic pines and oaks seem more common on these ridges. Soil moisture at the deeper levels may also have something to do with the character of this border zone formation, as soil water must drain away more rapidly through the exposed surface of the bluffs than in portions farther away from the lake.

B. Distribution of Pinus Strobus. In prehistoric times the sandy plains to the northeast of Point Betsie were covered with a heavy growth of Pinus Strobus. This was burned over before the arrival of the white man, who cut many of the trees which had been killed by the fire but which were still standing. From the testimony of the oldest inhabitants there are practically no white pines in the climax forest south of Point Betsie. From other observations it would seem that the beech-maple-hemlock forest extended in a strip 10 or 12 miles wide from Point Betsie south practically to the sandy plains east of Manistee. East of this strip white pine was the characteristic tree. The soil map indicates a region of glacial moraines, just about coterminous with this strip of hardwood forest, while east of this strip is a similarly extensive region of sandy soil. On the other hand, within the Crystal Lake Bar region the climax forest extends apparently without change from the glacial

soil northward over the fixed dunes to the northern edge of the moraine beyond Point Betsie.

C. The Relations of the Component Parts of the Climax Forest.

1. While the pine-oak stage is not a prominent feature of successions of northern Michigan, there are evidences of its former existence here in the oak and pine remnants found in the climax forest. These are rare, and are generally located as indicated above, on the more xerophytic summits of the ridges in the forest, whether on dune or glacial substratum.

2. The conditions for germination of maple and hemlock seeds seem to be rather different. The hemlock seems to be unable to germinate except on decaying wood. Practically the seedlings are usually found on decaying hemlock trunks, frequently as many as a dozen have reached the height of several feet on a single trunk, (Plate XI). On the other hand, the maple seems to need more light for successful germination, and abundance of maple seedlings is a common characteristic of the greater light supply produced by the fall of a large tree, and the consequent opening up of the forest crown.

3. Persistence in the open. When forest trees are left to grow in the open, or are planted in isolated positions, the maples seem to be the most successful. It is a popular saying that the hemlock will not grow where people walk over its roots, which apparently indicates that it needs the undisturbed conditions of the forest. The beech also is not a tree of the open, and seems to die readily where exposed on the edges of clearings. From these considerations it would seem as if the hemlock on the whole was the more shade tolerant, and therefore likely to become the final member of the climax forest, if left long enough in undisturbed conditions.

University of Chicago.

## LEGENDS.

| | | |
|---|---|---|
| Plate | VI. | Fig. 1. Fossil Beach, north of Pt. Betsie lighthouse.<br>Fig. 2. Shore bluffs with "crater" dunes perched on glacial plateau. |
| Plate | VII. | Pt. Betsie Dune Complex, showing typical blow-out on right; relic forest patches in background, and lighthouse and coast guard station. |
| Plate | VIII. | Beech-Maple Hemlock Forest on fixed dunes. |
| Plate | IX. | Interior view of Border-Zone formation. |
| Plate | X. | Exterior of relic forest patch on Pt. Betsie Dune Complex. |
| Plate | XI. | Interior of Climax Forest, showing hemlock seedlings on decaying log. |

With the exception of Plate VII, the originals of the above are by Dr. George D. Fuller of the University of Chicago.

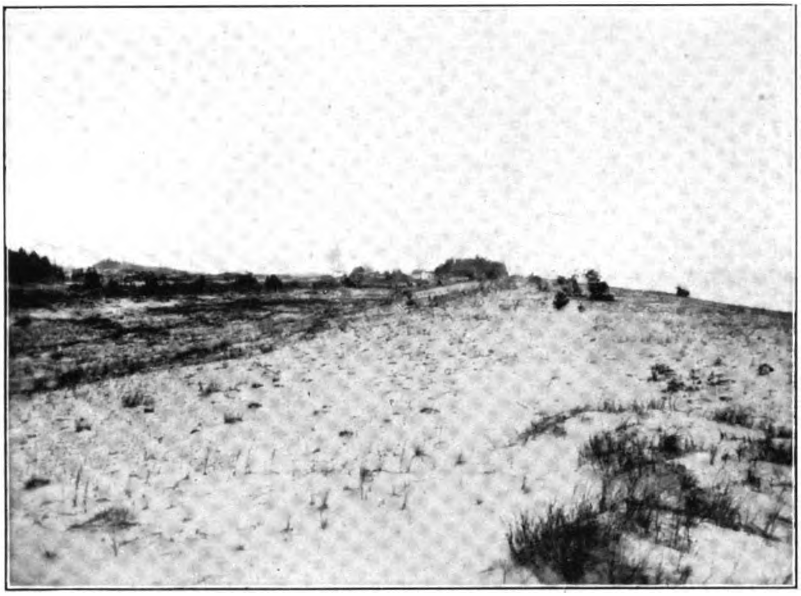


Figure 1.

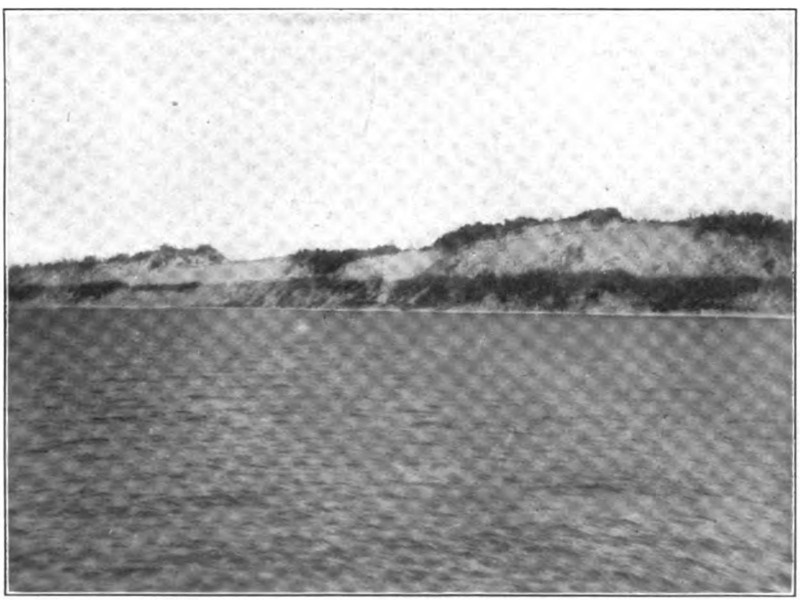
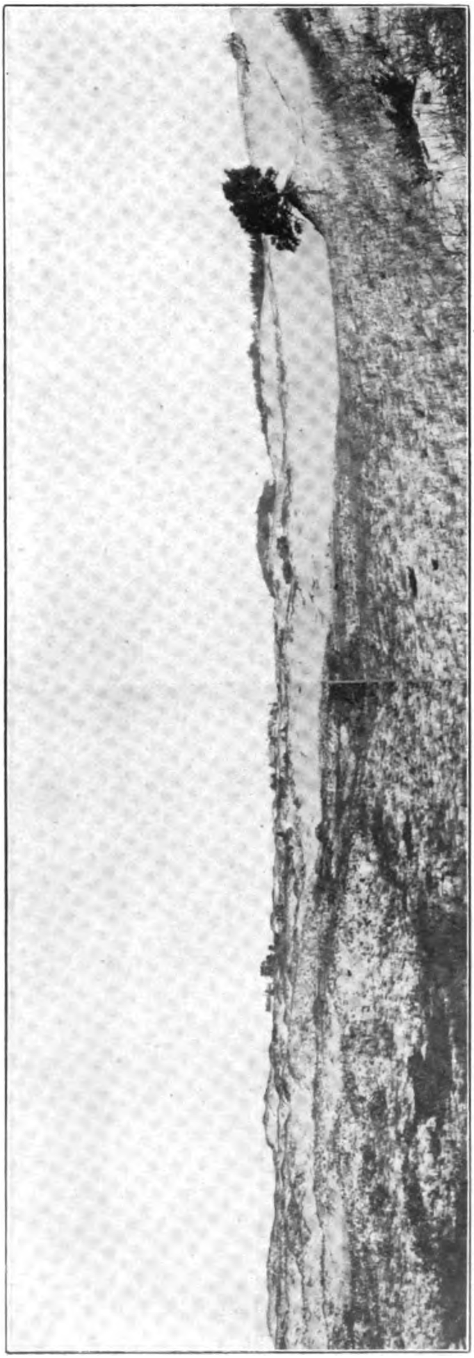
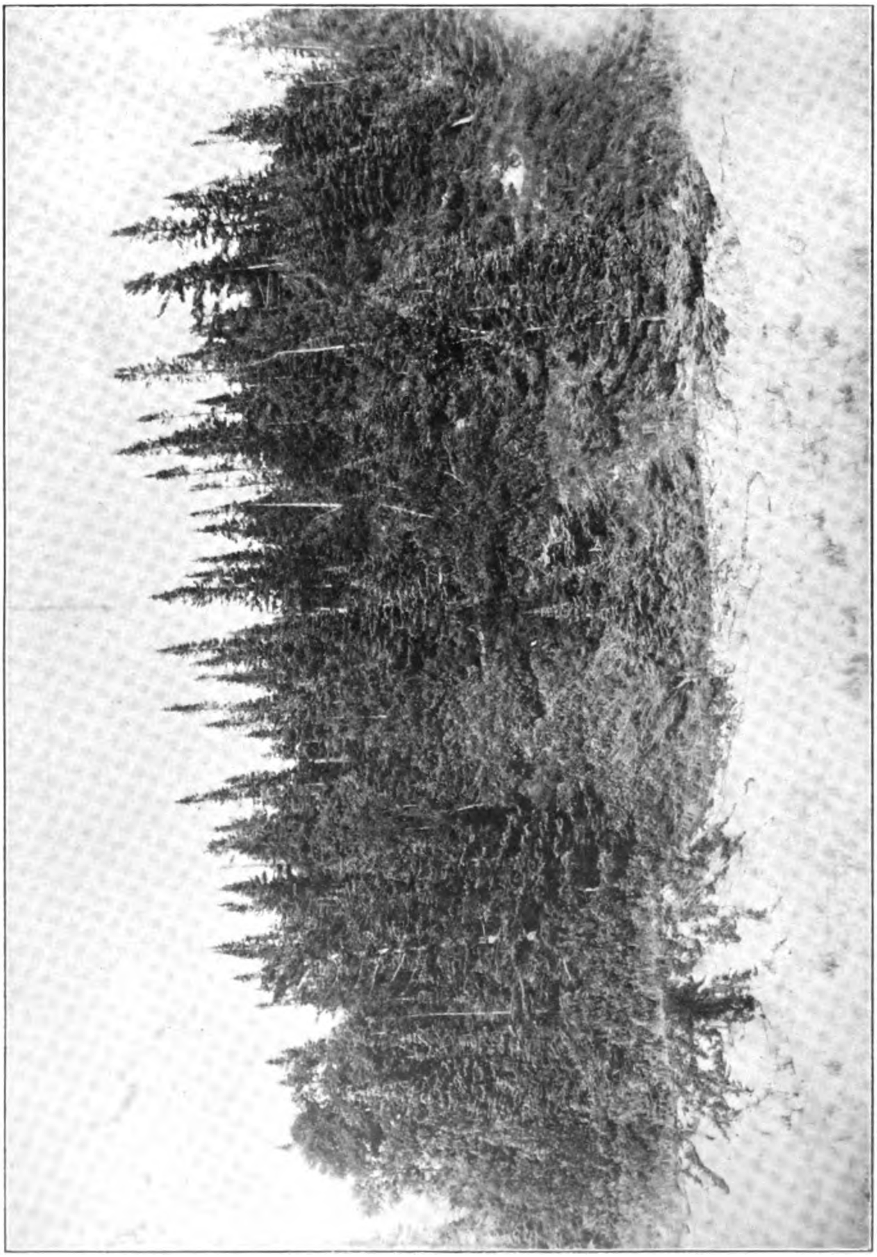


Figure 2.





# THE FOREST ASSOCIATIONS OF WAYNE COUNTY, MICHIGAN.*

BY FOREST B. H. BROWN.

## INTRODUCTION.

The work of collecting data upon the forest associations of Wayne County, Michigan, was started by the writer in 1902 and has been continued at vacation intervals as opportunity afforded since that date, until three hundred and fifty-three woodlots have been studied, the species of all woody plants and the important herbs being listed and ecologically considered. The nomenclature is that of Gray's Manual, 7th Edition.

From the lists and notes thus obtained, together with the information collected from the residents within whose memory the forests existed nearly intact, it has been possible to gain a fairly definite notion of the composition of the forest associations which covered the county prior to settlement, and to reconstruct and map such associations with considerable accuracy.

Considering the very level nature of the surface of this county, excluding a small part in the northwest corner, it may seem surprising to find the associations as diversified in character as will be shown in the treatment of which this paper is an abstract. It may be said that Wayne County almost eliminates the factors of topography from the usual complex of factors with which one has to deal in studying plant associations, so that the effect of other factors, such as soil, geological changes, etc., may be the more clearly observed. Wayne County affords almost ideal conditions to study the forest associations in relation to soil types, and the writer hopes to further the growing tendency among ecologists to recognize the importance of the plant association as an index of soil fertility.

As opportunity afforded, observations were made upon the people, density of population, and industrial development following the removal of the forests, and it was found that the races of people, type of farm buildings, kind of agriculture, and even the social development of the people on the site of the several forest associations now removed, were as distinct as the forest associations which had preceded them.

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19th Mich. Acad. Sci. Rept., 1917.
*Contribution from the Osborn Botanical Laboratory.

Probably the most obvious characteristic of the forest vegetation as a whole is the extreme variety of species composing many of the associations and the general dissimilarity between it and the usual upland type lying westward and mostly outside of the county. One may clearly observe this transition in going from Ann Arbor to Detroit. The change is abrupt and takes place a short distance west of Ypsilanti or some twenty miles west of the Detroit River, where the rolling morainal topography changes to the level glacial lake basin of which Wayne County, except the small northwest portion, is a part. The change is apparent in the shrubs and herbs, but particularly in the trees that now remain either scattered or grouped in woodlots. Many of the trees show by their age that they were part of the heavy and nearly unbroken forest which existed less than a century ago. People who remember the forest as it existed fifty years ago testify that there was an abundance of such trees as black walnut, whitewood *(Lirodendron Tulipifera)* and others which would have made the individuality of the forest more strongly marked then than at present. This type of vegetation covers a large and important part of southeast Michigan along that portion of the state bordering the St. Clair River, Lake St. Clair, the Detroit River, and Lake Erie. It occupies the glacial lake basin following the trend of the ancient beach lines in its western limits. Unpublished observations by Schaffner, Transeau, Sears, and others, make it evident that a similar distinction exists over this glacial lake basin which extends southward and eastward over northern Ohio, bordering Lake Erie. In a survey of the vegetation made by automobile they were enabled to mark the change of vegetation wherever they passed upon the basin area. Over the western morainal area, such as we observe about Ann Arbor, the hard maple and beech, in order of relative abundance, are characteristic trees. This is the climax forest, as recently given by Zon for this region. Over the eastward lake basin area occur a variety of associations, but we notice a marked absence of the hard maple-beech forest, except for a small area here and there, as in southeast Brownstown. Beech often occurs but, except for the small Plymouth-Northville district, it is associated with *Acer rubrum, A. saccharinum,* and other trees, forming a forest totally unlike that outside the basin, both in character and appearance.

### CHARACTERISTIC TREES.

The great variety of species occurring in several of the forest associations of Wayne County makes it difficult, at the outset, both to recognize some of the associations, particularly in the central north-to-south belt, and to follow the boundaries formed by the meeting of two associations,

each composed of over ten associated species, such as are commonly met with in the vicinity of Dearborn, Wayne, and numerous other places in the county, where it is not at all uncommon to count over twenty species of trees growing on a quarter of an acre.

The problem is greatly simplified by selecting those species which show the most marked tendency to be limited in local distribution to some given area. With this in view, ten species have been chosen as the ones most decidedly related in their local distribution in the county, to areas where certain optimum conditions exist more or less uniformly. They are believed to be the trees which are the most certainly confined to restricted areas, and it has been found that these ten trees indicate as many regions which, together, cover the county, yet do not overlap. These ten trees are assumed to be the most characteristic elements of all the forests of Wayne County, past, as well as present.

A portion of this number, like *Larix*, formed forests of pure growth or like-commensal forests; others, like sassafras, tend to form mixed forests or unlike-commensal forests; others, like hard maple, may form forests of pure growth, but also occur in forests of mixed growth. The list, therefore, falls under three headings, as indicated below:

### I. *Species tending to form like-commensal forests.*

These are formed by tamarack *(Larix laricina)*, birch *(Betula alba var. papyrifera)*, and aspen *(Populus tremuloides)*, giving us respectively, the tamarack forests, paper-birch forests, and aspen forests. Yet forests of pure growth are rare in Wayne County, occurring as small island-like patches here and there.

*Larix* is the most strongly social species of this region and tends, more than any other species, to form stands of pure growth. While the few isolated individuals found here and there in some portions of the county, usually in the vicinity of peaty areas, in Livonia, Greenfield, and other places, would suggest that the species may have been somewhat more common in the past than at present, it is not probable that the numerous lakes and ponds existing in the past, and now all reclaimed by vegetation, ever had the *Larix* forest stage in the filling-in process, so common in the kettle hole bogs farther inland. Such lakes and ponds, while numerous in the past throughout the northeast-southwest central sand drifted belt of the county, were invariably shallow and have all been reclaimed by vegetation, and, except for Yerkes Lake, near Northville, are now represented by beds of peat. An excellent example is found in northeast Brownstown, showing the final stage in the filling-in process. The peaty areas are covered by wet prairie, formed by social grasses or sedges. There is no evidence to show that such areas were ever occupied

by trees of any kind. The black oak forest meets the prairie so formed at a sharp line. The area covers nearly three square miles. Sand has so drifted as to form knolls, reaching above the level of the prairie, and there occur islands of black oak forests on these sand knolls, surrounded by prairie. The absence of all trees, even seedlings, on the prairie, indicates little or no advance of trees over the peat. This and many similar areas seem to have been treeless from the start. The peat is reported to be not over ten feet deep and in dry seasons is likely to take fire and burn to the bottom.

The aspen *(Populus tremuloides)* is social, showing a tendency to form stands of pure growth. The best example of this type begins on a swampy area, northwest of Wayne, and follows two miles northward. along the Wayne-Plymouth electric line on both sides of the track. The aspen forest is totally unlike any other of the region in appearance, and is one of the most noticeable features to be seen in the vegetation along this route. It is one of the best examples of a like-commensal forest. The total area of pure aspen in the county, however, is not large, although it is larger than that of any other gregarious species. Like the birch, it commonly mixes with other species. Portions of the aspen forest north of Wayne contain red maple, pin oak, *Populus deltoides*, and other trees, evidently pioneers of other associations, which are very slowly encroaching on the aspen.

A forest of exceptional interest begins well within the city limits of Detroit and extends northwestward and north, covering about forty square miles. It is characterized by paper birch which often forms over 65 per cent of the woods, as in the S. W. ¼, S. E. ¼, Sec. 16, Greenfield. Palmer Park and the west side of the Grand Lawn Cemetery wood preserve a portion of this association. The soil is sandy, of good to fair productiveness.

II. *Species tending to form both like- and unlike-commensal forests.*

The black oak *(Quercus velutina)* forms a thin forest sometimes called oak openings, upon sand which is light and dry and is blown by the wind. It is too poor for agriculture, at least under present methods. The people should plant poplar windbreaks and forest planting should be undertaken. The Norway pine *(Pinus resinosa)* should do well here.

An intimate relation exists between the black oak forest and the people and type of agriculture which has sprung up over the extensive area from which this forest association has been cleared. Here we find the barb-wire fence, the primitive log house and small barns. The people are generally Polish and distinct socially from those who farm where maple, beech, or any of the other forest associations described, have been removed. The conditions of soil which have supported begin-

ning stages of forest development make it difficult for the people to develop educationally or otherwise.

Another tree which occurs in forests of both mixed and pure growth is the hard maple *(Acer saccharum)*. In the townships of Northville and Plymouth, this tree is so dominant in places that secondary species are nearly excluded. The "sugar bush" is common. In other places, often in the same wood lot, it is associated with the beech. Throughout this area the walnut is very abundant, also the cherry *(Prunus serotina)*, but the predominating tree is hard maple. Zon considers this the climax forest, but this and one other locality, an area of about fourteen square miles in south Brownstown, are the only ones which actually fit into the scheme. A very large portion of this hard maple-beech forest has been cleared away and the land put under cultivation. Comparing now the kind of agriculture, type of farm buildings, and the people, with those of the black oak areas, we find the greatest contrast. Here are woven wire fences and large barns with silos, indicating good conditions for the keeping of stock, especially sheep. Corn and other crops requiring good soil can be raised; the people speak English; there is the atmosphere of thrift and hospitality, which we find upon the soils from which associations indicating fertility have been removed.

A third characteristic tree occurring in both mixed and pure associations, is the shag bark hickory *(Carya ovata)*, south of Trenton, on Slocum's Island. There are portions of these woods which are nearly pure hickory. The wood is well preserved, easily visited, a large portion being set aside as public ground, and is of rare interest. The associated species are *Carya alba, C. glabra, C. microcarpa, Quercus alba,* and *Q. rubra* and are present in portions of the wood lot where the stand is mixed.

The oak-hickory association tends also to form a rather narrow belt of varying width, but often less than one mile wide, along the extreme eastern part of the county along and near the shore; also, along the Huron, and to a less extent, along the River Rouge. The total area occupied by this association is not large enough to allow a distinct farming community to develop.

The sycamore also tends to form stands, both of pure growth, and mixed. The pure growth stands are small, a few hundred feet at most in extent and of recent origin, as if following a clearing. Pure stands of large diameter, suggesting that such stands occurred in the original forest, were not found. The tree seems to have occurred quite generally along with silver maple, elm, and red maple, and other wet land associations, to be described later. This mixed forest affords good evidence, showing the tolerance of the sycamore. In the S. E. ¼, S. E. ¼, Sec. 22,

Greenfield, the forest is composed of *Planatus occidentalis, Ulmus americana, Acer saccharinum, Fagus grandifolia, Fraxinus nigra, Quercus bicolor* and *Carpinus caroliniana,* in order of relative abundance. The stand is of typical density, the trees standing an average distance of twelve feet apart, showing a fair amount of tolerance for this species. But the tree invariably forms forests in physiologically wet habitats, on clay, loam or shallow sand, with or without humus, associated with hydrophytic species. It shows no tendency to form forests in the black oak habitat, although this forest is open and there is plenty of chance. The results do not sustain the conclusions of Griggs,* who has overlooked the fact that one of the crucial tests of a forest type is its ability to reproduce. The constant appearance of sycamore in the hydrophytic forests of the old lake bed area is one of the distinguishing features of this forest in south-east Michigan. The sycamore is also abundant on the flood plains of both the Huron and Rouge Rivers.

III. *Species tending to form unlike-commensal forests.*

Under this head are included those characteristic trees which, of themselves, show little or no tendency to occur in pure growth, but occur in association with other species. These are the beech, silver maple, and sassafras, each associating with certain other species and characterizing three different portions of the county. The forests characterized by each of these trees, respectively, are at once the largest and most characteristic types east of the Defiance Moraine. Together they are estimated to cover over 70 per cent. of the county. The silver maple occurs as the characteristic tree of the mixed forest on the flat, wet, and poorly drained glacial clay, or till plains, of the extreme eastern portion of the county, forming a belt extending north and south, at or near the shore line, and spreading inland a distance of one to seven miles. The belt covers Gratiot township and most of Grosse Point, city of Detroit, Springwells, Ecorse, and a portion of Monguagon and Brownstown. Gratiot, with an average slope of eight feet per mile, and Ecorse, with a slope of four feet per mile, and part of Detroit, with a slope of three feet per mile, afford ideal conditions for the growth of this forest.

The forest is quite uniform in composition, the numerous lists taken from different wood lots throughout the belt, showing a remarkable similarity in composition and relative abundance. The silver maple often forms over 50 per cent. of the stand. One wood lot listed in 1903 had nine species on one-fourth acre, in which the silver maple formed 71 per cent. of the stand. The most common secondary species of trees are *Ulmus americana, U. fulva, Fraxinus pennsylvanica, F. pennsylvanica* var. *lan-*

*Ohio Biological Survey, Bulletin 3, page 295.

*ceolata, Quercus bicolor, Tilia americana.* Westward from this belt, wood lots occur, showing an association of silver maple, elm, and ash; but these are easily distinguished as belonging to a different series. The elm is still prominent, but the silver maple becomes subordinate or almost absent. Red maple takes its place, becoming prominent. There is less red ash and more black; also it will be found that the association is seldom pure, but mixed with species clearly belonging to other types, the most common of which are the beech, soft maple, the oak-hickory, and sassafras associations.

As before mentioned, this association is one of the three largest in the county. It is composed of hydrophytic species and the forest occurs in situations too wet for agriculture. On clearing away the forest it was necessary to drain the land before it could be put under cultivation. This has been difficult to accomplish, because of the very level topography and it has been difficult to raise crops requiring early cultivation like corn. Pastures start late and conditions are not so well suited for the keeping of cattle, sheep, and other animals. The barns are of the roomy, symmetrical kind, suitable for storing hay, for this is good grass land. Wherever it has been possible to secure good drainage, cereals do well, as a rule.

A second large and fairly distinct forest association is composed of beech and red maple, in order of their relative abundance. This forms a wide, but somewhat interrupted belt, throughout the central portion of the county occurring in the east portion of Livonia, Nankin and Romulus townships, with extensions into Taylor, Dearborn and Redford. The association is entirely distinct in appearance from the hard maple-beech forest of the Northville region. The surface is level, the soil is clay, often loamy, with here and there a shallow covering of sand which interrupts the drainage, and causes local swamps.

The drainage problem has been quite generally and successfully solved and conditions are excellent for the raising of cereals; the farm buildings are of the kind best suited for the keeping of stock; the people are hospitable, interested in educational work, particularly with branches that have to do with the improvement of the soil and what it produces. It is surprising how people in the beech-red maple area, busied as they are in their daily work, actually study, and even accurately investigate, the conditions with which they have to deal. It is common to meet people here who know a good deal of plant physiology, soil-physics and chemistry, and can even talk intelligently about Mendel's Law. Conditions remind one strongly of the hard maple-beech area about Northville, but there is a difference. The hilly land in the Northville region, possibly because it interferes with the cultivation and harvesting of

crops, is often reserved for sheep pasture, and flocks of sheep are numerous here. Sheep are rather uncommon in the beech-red maple area.

The third and last great forest association occurring in Wayne County is a highly mixed one occurring on rather shallow sand and characterized by sassafras. The tree is associated with two others which are not quite so abundant or so uniformly distributed throughout the area, namely: *Quercus palustris* and *Nyssa sylvatica.* These three species, while not quite commensal, are rather closely associated. A careful study of this association leads to the conclusion that these are the three most characteristic species of this highly complex association. Thus a list of a quarter-acre area from any given place in the county where this association occurs, may disclose only one of the characteristic species; most frequently this will be sassafras, but may be either pin oak or *Nyssa* instead. The sassafras association is by far the most mixed association in the county. An excellent example is found on the S. E. ¼ of the S. W. ¼ of Sec. 32 Livonia. There are here twenty-two species within a quarter of an acre.

The two aspens, swamp oak, elm, red maple, Juneberry, bitternut hickory, butternut, wild plum, pin cherry, black cherry, and the viburnums are associate species. Dearborn and Wayne are in this association. The birch association is really an ecological equivalent. The association covers an important and large area through the sandy central portion of the county, alternating with the beech-red maple areas. The soil is moist in comparison with the black oak area. In places it is peaty. The varying soil conditions meet the demands of the market gardener. The farms are not large, the barns are small, where the labor is performed by hand. The people are of German or foreign descent. The problems with which these people have to deal are comparatively few, and there is a strong tendency for the people to follow tradition. They read little and miss a good deal of what is being done outside in the way of experimental investigations.

There have thus been indicated in order, all of the forest associations of any considerable size occurring in the county at the time of settlement by man. The present wood lots are the remaining portions of such associations, and as such are now fairly representative, although fast disappearing. Trees other than those listed occur, which, while local and not abundant, are yet of exceptional interest. Southeast of Dearborn, north of Wayne, and south of Belleville occur respectively three areas, each of about two square miles in extent, in which chestnut *(Castanea dentata),* predominates in the forest. A fourth smaller area occurs south and east of New Boston. It is confined exclusively to sand, usually in the

sassafras or black oak associations, but sometimes with beech and red maple. Also about one and one-half miles east of Plymouth, on the south bank of the Rouge, we see in plain sight from the Wayne-Plymouth electric line, a lone pine towering above the deciduous trees surrounding. This is a remnant of the white pine forest lumbered 28 years ago. There are eleven stumps remaining to tell the story, indicating the trees were 127 years old when cut. There can be no question but that this was original forest.

### SUMMARY AND CONCLUSIONS.

Having now completed the salient feature of the forest vegetation of the county, some of the more general interrelations existing between the associations, as a whole, and the environmental conditions may be pointed out.

Throughout the investigation it has been plainly evident, from a careful comparative study of the returns from the cultivated land in each of the several forest associations, that land from which any given forest association has been removed possesses agricultural possibilities distinct from land from which some other forest association has been removed, though the soil in the two areas, may look exactly alike. Such differences, clearly revealed by the vegetation and of extreme importance agriculturally, are as a rule, entirely overlooked by a soil survey, however carefully done. Thus the present soil maps do not distinguish between the black oak, the sassafras, and the beech-red maple association areas. They are classed together as sand on the soil map. Very numerous other instances might be mentioned.

The forest associations may be arranged in the following order: (1) Black Oak, (2) Sassafras, Birch, (3) Hickory, (4) Hard Maple, (5) Beech, (6) Silver Maple, (7) Sycamore. This gives us a gradient scale of forest associations that may serve to indicate the degree of soil fertility, being too dry at one extreme for successful agriculture, and too wet at the other. The optimum conditions for most crops occur in the maple-beech portions.

The several associations covering most of the old lake basin area are believed to be stages of forest development tending toward the hard maple-beech association as a climax. But the change is and has been exceedingly slow, due to the correspondingly slow topographic changes occurring on this area. So slow are the topographic and soil changes occurring naturally on this area that the forest has been become arrested in its development and the several associations represent the arrested stages, the succession of which will be published in the more complete account.

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# FLORA OF A WAYNE COUNTY SALT MARSH.

BY FOREST B. H. BROWN.

East of the Mulkey Salt Works, Ecorse, Sec. 28, occurs a salt marsh of several acres, which the writer visited in 1918. The marsh partly surrounds a well, drilled over twenty years ago, and is evidently the same as the saline region at Oakwood, visited by Farwell and other Detroit botanists in 1915 and reported upon in Rhodora for December, 1916 (**18**:243, 244). The following plants were observed in the marsh:

*Salicornia europaea* L.
*Atriplex patula* L. var. *hastata* (L.) Gray.
*Spartina patens* (Ait.) Muhl.
*Agropyron repens* (L.) Beauv.
*Polygonum aviculare* L.
*Agrostis alba* L.
*Hordeum jubatum* L.
*Danthonia spicata* (L.) Beauv.
*Melilotus alba* Desv.

The first three are most abundant and grow under conditions of extreme salinity. The others occur where soil is still saline but not so wet. Farwell mentions *Salicornia europaea,* and also such characteristic salt marsh plants as *Pluchea camphorata* and *Aster subulatus,* but it is somewhat remarkable that he makes no allusion to the equally characteristic *Spartina patens,* one of the most abundant plants in the area and heretofore unreported from Michigan so far as the writer knows.

No exact data could be obtained to account for the origin of these plants, but, if salt springs were present before the drilling of the well over twenty years ago, they may have preserved this association of salt plants which was subsequently extended by overflow from the well.

Osborn Botanical Laboratory, Yale University.

19th Mich. Acad. Sci. Rept., 1917.

# A METHOD FOR DETERMINING THE FUNGICIDAL COEFFICIENT OF LIME SULPHUR AND OTHER COMMON FUNGICIDES.

BY HARRY C. YOUNG AND E. H. COOPER.

## INTRODUCTION.

The physiological effect produced upon fungous spores by the great number of substances used at present or in the past as fungicides, has been made the basis of a wide series of investigations. These studies have naturally divided themselves and have been conducted along two distinct lines.

The first of this work taken up aimed at determining in the laboratory the exact action of various fungicides upon the germination of fungus spores. It was conceded that the effectiveness of fungicides depended upon their ability to either prevent spore germination altogether, or to cause the death of the young mycelium after its appearance. Exposure of spores to solution of various types and strengths was the fundamental factor in work of this kind.

Attention was first turned to laboratory methods which as near as possible, approximated field conditions. An attempt of this nature was made by Blodgett, Wallace and Hesler (10) in 1911. The laboratory tests carried out by them are in brief as follows. They worked in the main with lime sulphur solutions. Slides were sprayed with the fungicidal mixture and then were exposed to the air until the coating had dried thoroughly. A few drops of water containing viable spores of the fungus were put on the slide. Only one side of this slide was sprayed the other side being left as a check. The slides were then placed in a moist chamber long enough for the spores to germinate. The microscope was then used for determining the comparative fungicidal values of the various mixtures. These tests are supposed to represent as nearly as possible exact field conditions. No definite values can be placed on fungicides in terms of a standard by this method, as the process of drying would cause various chemical changes, thereby strengthening or weakening their fungicidal properties. However the plan gives better results than could be had by field tests as in the latter too many factors enter in.

19th Mich. Acad. Sci. Rept., 1917.

Previous to the work given above, Burrill[2] described a method in which spores were placed directly in a solution of Bordeaux mixture and after a specified time sprayed on a slide. The determination was made just as in the above method. The two methods seem to be almost alike, yet the results in each were very different. The reason for this great difference is explained by Cavenaugh who gives us the chemical changes in lime sulphur as used in the first method. When the solution comes in contact with the oxygen and carbon dioxide of the air a solid material is formed. The calcium tetra- and panta-sulphides ($CaS_4$ and $CaS_5$) are oxidized to thio-sulphate ($CaSO_4$), and later to sulphite ($CaSO_3$), sulphate ($CaSO_4$) along with some free sulphur and other compounds. In this way insoluble compounds are produced which are many times less effective in preventing spore germination then the solution would be if unexposed to the air. It has been proven, as the chemical analysis would indicate, that lime sulphur is more than two hundred times as effective in preventing spore germination when unexposed to the air.

The other method of determining fungicidal efficiency consists in elaborate and extended field tests. This necessitates the use of experimental plots either large or small, containing the plants to be used, considerable apparatus, much labor and longer or shorter periods of time, depending upon the nature of the plants used. However, no standard of comparison could be worked out as too many uncontrollable factors must be dealt with.

The work upon which this paper is based has been confined exclusively to the problems of arriving at a satisfactory laboratory method of determining fungicidal values based upon a definite standard. The object was to perfect a method by which various chemicals could be tested, and their fungicidal value determined in terms of some definitely known compound the action of which was sufficiently stable and uniform to merit its adoption as a standard. In this way it would be possible to determine the efficiency of a new or little known fungicide by means of a direct comparison with the standard and thus obtain its relative value as a fungicide. In other words the attempt has been made to perfect a method by which fungicides may be "standardized." To the writers' knowledge no method of this kind has hitherto been formulated.

In the province of hygienic bacteriology, the problem of the standardization of disinfectants has been made the object of extended study and experimentation.

A method for standardizing disinfectants was advanced by Rideal and Walker[6] in 1903. This method makes use of the varying ability of B. typhosus to resist the action of phenol when exposed to several different concentrations, for definite, though varying periods of time.

The resistance of B. typhosus to the compound to be tested is determined in the same manner and simultaneously with the phenol test. Beef extract broth is used as the culture medium. The phenol coefficient of the compound tested is then obtained by "dividing the figure indicating the degree of dilution of the disinfectant that kills the organism in a given time by that expressing the degree of dilution of the carbolic acid (phenol) that kills the same organism in the same time under exactly similar conditions. Table No. 1 will make clear the method of determining the coefficient of a disinfectant according to the Rideal-Walker method.

Table No. 1. Rideal-Walker Method.

Name, (A).
Temperature of medication, 20 degrees C.
Cultures used, B. typhosus, 24 hour, extract broth filtered.
Proportion of culture and disinfectant, 0.1 cc. plus 5 cc.

| Sample. | Dilution. | Time culture exposed to action of disinfectant for minutes. | | | | | | Phenol coefficient. |
|---|---|---|---|---|---|---|---|---|
| | | 2½ | 5 | 7½ | 10 | 12½ | 15 | |
| Phenol | 1:90 | X | — | — | — | — | — | |
| | 1:100 | X | X | X | — | — | — | 100/550 |
| Disinfectant "A" | 1:500 | X | X | — | — | — | — | |
| | 1:550 | X | X | X | — | — | — | 5.5 |
| | 1:600 | X | X | X | X | — | — | Coefficient |

X Signifies growth; — signifies no growth.
This table taken from Bulletin No. 82 Hygienic Laboratory.
Public health and Marine-Hospital Service of the United States.

Following this the Lancet[5] Commission, Report 7, advanced a method for standardizing coefficients. As in the Rideal-Walker method phenol at varying strengths is used as the standard solution. B. coli instead of B. typhosus is used as the test organism and McConkey's Bile Salt Medium instead of Beef Bouillon, as the culture medium. The reason for using this as a standard is that the organism is non-pathogenic and the medium will give constant growth characteristics for the organism. Twenty-four hour old cultures were used. The risk of misleading results from accidental contamination was almost entirely eliminated by the use of McConkey's medium. The carbolic (phenol) coefficient is determined by the Lancet method as follows: The figure representing the percentage strength of the weakest killing dilution of the phenol is divided by the figure representing the percentage strength of the weakest killing dilution of the unknown disinfectant, both at one and one-half and thirty minute exposures. The mean resulting figure is taken as the true coefficient.

By combining the more desirable points of the Rideal-Walker and Lancet methods, Anderson and McClintic of the United States Hygienic

Laboratory formulated a third method which seems to be the most satisfactory of any yet worked out. The Hygienic Laboratory method, as it is called, is essentially the method employed by the Lancet Commission with certain modifications. In this method the organism used is B. typhosus, a twenty-four hour culture in a beef extract broth showing a reaction to phenolphthalein of + 15 Fuller's scale. The cells are exposed to the action of the properly diluted disinfectant to be tested and of the phenol control. Plantings of the exposed organisms are made in standard beef extract broth every two and one-half minutes up to and including 15 minutes. A standard temperature of 20° C. is adopted for the experiment, and is maintained by a properly regulated water bath. To determine the phenol coefficient "the figure representing the degree of dilution of the weakest strength of the disinfectant that kills within two and one-half minutes is divided by the figure representing the degree of dilution of the weakest strength of the phenol control that kills within the same time. The same is done for the weakest strength that kills within 15 minutes. The mean of the two is the coefficient." This method of determining the coefficient is taken in Table 2 taken from Anderson and McClintic.

Table No. 2.

Name, "A."

Temperature of medication, 20° C.

Culture used, B. typhosus, 24-hour, extract broth, filtered.

Proportion of culture and disinfectant, 0.1 cc. + 5 cc.

| Sample. | Dilution. | Time culture exposed to action of disinfectant for minutes. | | | | | | Phenol coefficient. |
|---|---|---|---|---|---|---|---|---|
| | | 2½ | 5 | 7½ | 10 | 12½ | 15 | |
| Phenol | 1:80 | — | — | — | | | | $\dfrac{\dfrac{375}{80} + \dfrac{650}{10}}{2} =$ |
| | 1:90 | + | — | — | — | | | |
| | 1:100 | + | + | + | — | — | — | |
| | 1:110 | + | + | + | + | + | — | |
| | | | | | | | | $\dfrac{4.69 + 5.91}{2} =$ |
| Disinfectant "A" | 1:350 | — | — | — | — | | | |
| | 1:375 | — | — | — | | | | |
| | 1:400 | + | — | — | — | | | 5.30 |
| | 1:425 | + | + | — | — | — | — | |
| | 1:450 | + | + | — | — | — | — | |
| | 1:500 | + | + | — | — | — | — | |
| | 1:550 | + | + | + | — | — | — | |
| | 1:600 | + | + | + | + | — | — | |
| | 1:650 | + | + | + | + | + | — | |
| | 1:700 | + | + | + | + | + | + | |
| | 1:750 | + | + | + | + | + | + | |

### METHOD.

Consideration of the various methods for the laboratory determination of the fungicidal value of various fungicides and the germicidal value of disinfectants seemed to indicate that a method somewhat similar

to that of Anderson and McClintic for disinfectants might be worked out for fungicides. The attempt has been made, therefore, to perfect a satisfactory method, by means of which the relative values of various substances used as fungicides can be determined in terms of a copper sulphate solution of a standard strength. It is necessary to point out in this connection that this method is wholly arbitrary and that the many obscure chemical changes which may take place in fungicides (especially lime sulphur), when used in this way, have not been studied. No attempt has been made to determine the chemistry of the toxic effect on fungus spores of the several solutions utilized. Definite and uniform results under fixed conditions have been sought but the physiological and chemical reasons for these results have not been considered within the scope of the present work.

In order that any method may become effective different workers must follow definite standards such as this paper attempts to establish. One of the first factors to be taken into consideration is the test organism. It was desirable, however, that the forms should be those producing well known diseases, that they should grow abundantly and rapidly in culture with a large spore production, and that growth in culture should present definite and quickly recognized characteristics. Four organisms were selected which seemed to offer certain of these advantages: Sclerotinia fructigena (Pers.) Schi from apple, Glomerella rufomaculans (Berk.) S & S., Rhizopus nigricans, Ehr. and Endothia parasitica (Murrill) Anderson. The first one of these to be eliminated was S. fructigena because the lightness of the spores prevented them from going into suspension well. Rhizopus nigricans offered many advantages but its extreme resistance to the action of the fungicides used and to the copper sulphate standard led to its being discarded. G. ruformaculans proved to be very satisfactory in many respects, an important objection to its use being the probable existence of strains physiologically different.

For the test of this organism a culture was isolated from fruit taken from the North Carolina State College orchard and another was received from the Department of Botany of the Massachusetts Agricultural College. Table No. 3 shows the differences in resistance of the two cultures.

Table No. 8. Strains of Glomerella.

Temperature of the experiment, 18° C.

Culture, Glomerella rufomaculans grown on potato agar.

Portion of spore suspension and fungicide for plant, 0.2 cc.

Age of culture, eight days.

Amount of nutrient agar per plate, 10 cc.

| Fungicide. | Dilution. | Time culture exposed to action of fungicide (10% copper sulphate) minutes. | | | |
|---|---|---|---|---|---|
| | | 5 | 15 | 30 | 45 |
| Culture from M. A. C. College | 1:5 | O | O | O | O |
| | 1:10 | X | X | O | O |
| | 1:15 | X | X | O | O |
| | 1:20 | X | X | X | O |
| | 1:30 | X | X | X | X |
| Culture from N. C. Orchards | 1:5 | O | O | O | O |
| | 1:10 | O | O | O | O |
| | 1:15 | X | O | O | O |
| | 1:20 | X | X | O | O |
| | 1:25 | X | X | X | O |
| | 1:30 | X | X | X | X |

X Signifies growth; O signifies no growth.

From this experiment it cannot be definitely ascertained whether these were two strains or whether the North Carolina culture was more resistant because it had been more recently isolated. Unfortunately shortly after this the North Carolina culture was lost and all the results given in this paper are obtained from the use of the Massachusetts culture. The difference in the resistance of the two indicate strongly the necessity of using a standard organism. Either of these causes would tend to disqualify G. rufomaculans as a test organism.

Endothia parasitica is better adapted to this work in some respects than any of the other forms tested. Its slow growth, great susceptibility to the action of lime sulphur, and variation in spore resistance, are the disadvantages met with in its use.

Both G. rufomaculans and Endothia parasitica were used as test organisms but were tested separately, the two being used for comparison only.

### MEDIUM.

As potato agar is as well known and commonly used nutrient for the culture of many fungi, this medium seemed to be best suited for work of this nature. Hence a medium prepared according to the following formula was used throughout the work:

Finely cut peeled potatoes, 390 grams.
Distilled water, 1000 cc.
Heat in autoclave for 20 minutes at 15 pounds pressure.

Fifteen grams of shredded agar were added to each liter of this filtered decoction. The reaction of the medium was corrected to read +10 Fuller's scale.

### TEMPERATURE.

It was necessary to fix standard temperature for different parts of the experiments. The cultures were grown at a temperature of 28° C. All plantings were made into melted agar cooled to a temperature of 40° C. Room temperature was used at the point at which spore suspensions were exposed to the action of the fungicide. Attention should be called to the fact that the precautions against the variations in the temperature of the spore suspension during the exposure, found necessary by Anderson and McClintic are apparently unnecessary in this work. Ordinary variations of a few degrees had no effect. The plates were incubated at 28°.

### AGE OF CULTURES.

The spores of the organisms tested were obtained from cultures on potato agar slants. With G. rufomaculans 4-8 day cultures were tested. Results indicated that there was no difference in the resistance of spores from four-day cultures when compared with those obtained from cultures of eight-day growth. Spores from eight- to fifteen-day cultures exhibited a much greater resistance to the fungicides than those obtained from a four- to eight-day incubation. Because of the slower growth and spore production of E. parasitica it was found necessary to use cultures at least eight days old. Cultures of this organism between eight and twelve days' growth were tested but no difference in spore resistance could be detected. A definite standard of five days' growth for G. rufomaculans and ten days for E. parasitica, is recommended.

### FUNGICIDES.

Copper sulphate was selected as the standard compound for the determination of the fungicidal coefficient. This is a stable compound not subject to variation and change due to exposure to air or when greatly diluted. A one per cent solution was first used as approximating the per cent of copper sulphate used in preparing Bordeaux mixture. An extended series of preliminary experiments showed conclusively that a stronger solution was necessary as a basis for dilution. A 10 per cent solution was substituted. With E. parasitica as the test organism a 20 per cent solution was found necessary.

Seven different commercial mixtures of lime sulphur were used and a dilution of 1-40 made the standard regardless of the Beaume reading, or chemical composition. The samples of the lime sulphur were secured directly from the company in one gallon lots. In the booklets published by the various companies it was found that the dilutions recommended for spray were practically the same.

Two copper fungicides were tested, viz., Ammoniacal copper carbonate and neutral copper acetate. The ammoniacal copper carbonate solution was made as follows:

Copper carbonate, 1.48 grams.
Ammonia 26° Beaume, 15 cc.
Water, distilled, 20 cc.

The great concentration of this solution was necessary in order to obtain in the dilutions the killing point of the spores. In the same way a saturated solution of neutral copper acetate was necessary as a basis for dilution.

### PROCEDURE.

As has already been suggested the method advanced by Anderson and McClintic has been made the basis for the development of the method of testing fungicides which is recorded in this paper. Radical modifications have been necessary because of the wide differences between bacteria and fungus spores. Briefly stated the method consists in suspending in distilled water the fungus spores to be tested. Measured portions of this suspension are exposed for definite periods of time to the fungicide to be tested and to the copper sulphate standard. Definite amounts of the spores thus exposed are introduced into tubes of melted agar and then poured into plates. These plates are incubated for four days and then examined for growth. A constantly recurring trouble in the early stages of the work was the difficulty encountered in introducing a sufficient number of spores into the diluted fungicide for exposure and the subsequent introduction of the exposed spores into the tube of melted agar. A platinum loop of the type used by Anderson and McClintic could not be depended upon to introduce the spores. A platinum spoon gave but little better results. Sterile pipettes graduated to .1 cc. were finally used and gave uniform plantings when .1 to .2 cc. of the dilution were used. A large number of sterile pipettes is necessary for each pipette must be sterilized before being used again.

Dilutions of the fungicide were made twice as strong as the subsequent exposure required. This allowed for the introduction of the spore suspension which was calculated to reduce the strength of the fungicide one-half.

The spore suspension was made by adding several cubic centimeters of sterile distilled water to an agar slant culture of the organism to be used. The culture was then agitated gently in order to suspend the spores in the water. One cc. of the spore suspension was then introduced into a sterile, cotton plugged test tube by means of a sterile pipette. In this tube had been placed previously 1 cc. of the properly diluted fungicide. This brought the fungicide to the desired dilution.

The periods for which the spores were subjected to the action of the fungicide were 5, 15, 30 and 45 minutes. At the end of each of these periods, .2 cc. of the dilution containing the spores was introduced into each of two tubes containing 10 cc. of melted agar cooled to a temperature of 40° C. These tubes were shaken thoroughly to disseminate the spores throughout the medium, and their contents at once introduced into sterile petri dishes. A check plate containing spores from the untreated spore suspension was also poured. The plates were allowed to solidify, were labeled and incubated for four days at 28° C.

It was found by carefully arranging the work that four or five different dilutions could be carried on at one time. Dilution tubes, properly labeled, and in wire test tube racks, greatly facilitated the operation. Each rack was placed immediately in front of the investigator. At his right should be placed a copper container with sterile pipettes. The tubes containing melted agar were placed in a water bath regulated to maintain a constant temperature of 40° C. Sterile petri dishes were placed within easy reach and a receptacle for the poured plates placed to the left of the worker. Too much emphasis cannot be placed upon the proper arrangement of all material and apparatus. Upon this depends accuracy and speed in manipulation. Once a series of exposures has been started no time is open for rearranging equipment or replenishing the supply of agar, pipettes, and other necessary material.

In developing the method it was found that several preliminary tests were necessary in order to determine the approximate dilution strength at which the fungicide would check spore germination and growth. This point varies considerably with different fungicides and with the spores of different organisms. A series starting at a dilution of 1-5 or 1-10 and carried through at intervals of 50 up to a final dilution of 1 to 300 or in the case of lime sulphur, up to 1 to 700, with a uniform exposure of 15 minutes usually gave the range within which germination was prevented. Table No. 4, in which G. rufomaculans was used with Ammoniacal copper carbonate, shows the results from a preliminary test of this kind.

Table No. 4.

Fungicide, Ammoniacal copper carbonate, 100x standard.
Organism, G. rufomaculans on potato agar.
Age of culture, four days.
Amount spore suspension and fungicide per plate, .2 cc.
Amount potato agar per plate, 10 cc.
Temperature of incubation, 28° C. for four days.
X=growth.
O=no growth.

| Ammoniacal Copper carbonate 100x standard. | Time of exposure in minutes. | Dilutions. | | | | |
|---|---|---|---|---|---|---|
| | | 1-5 | 1-75 | 1-100 | 1-200 | 1-300 |
| | 15 | O | X | X | X | X |

The results shown in the table indicate that the points to be determined will lie between the dilutions 1-5 and 1-75 for the 15 minutes' exposure. The 45- and 5-minute exposures would be likely to call for a greater or less dilution respectively, but ought at least to fall within the dilutions 1-1 and 1-100. This was later found to be the case.

## RESULTS.

A series of preliminary tests similar to the one mentioned above were performed with Bowker's Lime Sulphur. From these tests dilutions of the 1-40 standard from 1-200 to 1-300 with intervals of 20 were determined upon. The 10% copper sulphate standard was prepared in dilution from 1-5 to 1-35 with intervals of 5. Treatment of the spores of Glomerella rufomaculans according to the method stated above gave the results shown in Table 5.

Similar tests, using G. rufomaculans, were made with the following lime sulphur preparations: Dow Chemical Co., Grasseli Chemical Company, Thomas Chemical Co., Sherwin Chemical Company, Blanchard Chemical Company, and the South Haven Chemical Company. The results obtained from these tests are embodied in Table 5.

Table No. 5.

Temperature of exposure, 18°-21° C.
Cultures, Glomerella rufomaculans (cingulata) on potato agar.
Age of cultures, 4-8 days.
Amount of spore suspension and fungicide per plate, 0.2 cc.
Amount of potato agar per plate, 10 cc.
Temperature of incubation, 28° C. for four days.

X=growth.

O=no growth.

| Fungicide. | Time of exposure (in min.) | Dilutions. 1-200 | 1-220 | 1-240 | 1-260 | 1-280 | 1-300 | 1-320 | 1-340 | Copper sulphate coefficient. For copper sulphate figures see last series in tables. |
|---|---|---|---|---|---|---|---|---|---|---|
| Bowker | 5 | O | O | X | X | X | X | | | $\frac{\frac{220}{5}+\frac{260}{25}}{2}=29.2$ |
| Chemical Co. | 15 | O | O | X | X | X | X | | | |
| L. S. | 30 | O | O | O | X | X | X | | | |
| dil. 1-40 | 45 | O | O | O | O | X | X | | | |
| Dow | 5 | O | X | X | X | X | X | | | $\frac{\frac{200}{5}+\frac{260}{25}}{2}=25.2$ |
| Chemical Co. | 15 | O | O | X | X | X | X | | | |
| L. S. | 30 | O | O | O | O | X | X | | | |
| dil. 1-40 | 45 | O | O | O | O | X | X | | | |
| Graselli | 5 | O | O | X | X | X | X | X | X | $\frac{\frac{240}{5}+\frac{320}{25}}{2}=30.4$ |
| Chemical Co. | 15 | O | O | O | O | X | X | X | X | |
| L. S. | 30 | O | O | O | O | O | O | X | X | |
| dil. 1-40 | 45 | O | O | O | O | O | O | O | X | |
| Thomsen | 5 | O | O | X | X | X | X | X | | $\frac{\frac{220}{5}+\frac{300}{25}}{2}=28$ |
| Chemical Co. | 15 | O | O | O | X | X | X | X | | |
| L. S. | 30 | O | O | O | X | X | X | X | | |
| dil. 1-40 | 45 | O | O | O | O | O | O | X | | |
| Sherwin & Williams | 5 | O | X | X | X | X | X | X | | $\frac{\frac{200}{5}+\frac{280}{25}}{2}=25.6$ |
| Chemical Co. | 15 | O | O | X | X | X | X | X | | |
| L. S. | 30 | O | O | O | O | O | X | X | | |
| dil. 1-40 | 45 | O | O | O | O | O | X | X | | |
| Blanchard | 5 | O | O | X | X | X | X | X | | $\frac{\frac{220}{5}+\frac{300}{25}}{2}=28$ |
| Chemical Co. | 15 | O | O | X | X | X | X | X | | |
| L. S. | 30 | O | O | O | X | X | X | X | | |
| dil. 1-40 | 45 | O | O | O | O | O | O | X | | |
| South Haven | 5 | O | O | X | X | X | X | X | | $\frac{\frac{220}{5}+\frac{280}{25}}{2}=27.6$ |
| Chemical Co. | 15 | O | O | O | X | X | X | X | | |
| L. S. | 30 | O | O | O | O | X | X | X | | |
| dil. 1-40 | 45 | O | O | O | O | O | X | X | | |

| | | Dilutions of Copper Sulphate. 1-5 | 1-10 | 1-15 | 1-20 | 1-30 | 1-40 | 1-50 | 1-60 | Copper sulphate coefficient. |
|---|---|---|---|---|---|---|---|---|---|---|
| Ammoniacal | 5 | O | O | O | O | X | X | X | X | $\frac{\frac{20}{5}+\frac{50}{25}}{2}=3.0$ |
| Copper Carbonate | 15 | O | O | O | O | O | X | X | X | |
| 100x standard | 30 | O | O | O | O | O | O | X | X | |
| | 45 | O | O | O | O | O | O | O | X | |
| Neutral | 5 | O | X | X | X | X | | | | $\frac{\frac{5}{5}+\frac{10}{25}}{2}=.7$ |
| Copper Acetate | 15 | O | X | X | X | X | | | | |
| Saturated | 30 | O | O | X | X | X | | | | |
| Solution | 45 | O | O | O | X | X | | | | |

| | | Copper Sulphate Dilutions. 1-5 | 1-10 | 1-15 | 1-20 | 1-25 | 1-30 | 1-35 |
|---|---|---|---|---|---|---|---|---|
| Copper Sulphate | 5 | O | X | X | X | X | X | X |
| Standard | 15 | O | O | O | X | X | X | X |
| 10% solution | 30 | O | O | O | O | X | X | X |
| | 45 | O | O | O | O | O | X | X |

The figure known as the copper sulphate coefficient given in the tables represents the relative spore killing power of a given fungicide as compared with that of a known strength of copper sulphate in the same periods of time and under exactly the same conditions. In the calculation of this coefficient, the Anderson and McClintic method is used. The copper sulphate coefficient is arrived at by dividing the figure representing the degree of dilution of the weakest strength of the fungicide used that kills within five minutes by the figure representing the degree of dilution of the weakest strength of the copper sulphate solution which kills within the same time. The same is done for the weakest strength that kills within 45 minutes. The mean of the two is the coefficient.

In the work with lime sulphur compounds the dilutions were so great that variable results occurred. These results were probably dependent upon obscure chemical changes that took place at this dilution. For this reason the coefficient of lime sulphur is likely to be more or less variable even when the same standards are used in the experiment. These differences, however, are not so great but that the coefficients are of some value in comparing with each other the various commercial mixtures of lime sulphur.

Two copper fungicides, ammoniacal copper carbonate and neutral copper acetate were tested, and coefficients determined. The results and coefficients obtained are shown in Table No. 5.

The copper fungicides showed much less variations in their action than was the case with lime sulphur preparations. This was undoubtedly due, at least in part, to the fact that both ammoniacal copper carbonate and neutral copper acetate are relatively stable compounds, and for that reason not subject to the great variation in dilution that was exhibited by the lime sulphur preparations. The coefficient really indicates the difference in toxic effect of different copper compounds. The fact that ammoniacal copper carbonate gives a positive coefficient of three may be due to some extent to the free ammonia present in the dilutions. But for the fact that the solution was made so strong, a fractional coefficient might have been calculated as was the case with neutral copper acetate.

When E. parasitica was substituted for G. rufomaculans as the test organism several rather unlooked-for facts were brought out. The spores of this organism proved highly susceptible to the lime sulphur mixtures, but on the other hand were extremely resistant to the action of the copper sulphate standard. It will be seen from Table No. 6 that the dilutions of the one to forty standard run from 1-800 up to 1 to 600. On the other hand a 20% solution of copper sulphate had to be substituted for the 10% solution used with G. rufomaculans and even then the killing point in the five-minute period was at the 1-1 dilution. These

facts necessarily gave an extremely large copper sulphate coefficient. For example, the coefficient given by Bowker's product with G. rufomaculans as the test organism, was 29.2, whereas with E. parasitica the same mixture gave a coefficient of 160. In reality the difference is even greater than the figures indicate for the copper sulphate standard in the first was a 10% solution while in the second a 20% solution was used.

As would be expected there was no such discrepancy exhibited when E. parasitica was used as the test organism with the copper fungicides. Table No. 6 shows the results with the two copper compounds using a 20% copper sulphate solution as a standard.

Table No. 6.

Temperature of exposure, 18°-21° C.
Cultures, Endothia parasitica on potato agar.
Age of Cultures, 8-10 days.
Amount of spore suspension and fungicide per plate, 0.2 cc.
Amount of potato agar per plate, 10 cc.
Temperature of incubation, 28° C. for eight days.
X=growth.
O=no growth.

| Fungicide. | Time of exposure (in min.) | Dilutions. 1-300 | 1-350 | 1-400 | 1-450 | 1-500 | 1-550 | 1-600 | Copper sulphate coefficient. |
|---|---|---|---|---|---|---|---|---|---|
| Bowker | 5 | O | X | X | X | X | | | $\frac{\frac{300}{1}+\frac{400}{20}}{2}=160$ |
| Chemical Co. | 15 | O | O | X | X | X | | | |
| L. S. | 30 | O | O | O | X | X | | | |
| dil. 1-40 | 45 | O | O | O | X | X | | | |
| Grasselli | 5 | O | O | X | X | X | X | X | $\frac{\frac{350}{1}+\frac{550}{20}}{2}=188.5$ |
| Chemical Co. | 15 | O | O | O | O | X | X | X | |
| L. S. | 30 | O | O | O | O | O | X | X | |
| dil. 1-40 | 45 | O | O | O | O | O | O | X | |
| Copper Sulphate Standard | | 1-1 | 1-5 | 1-10 | 1-15 | 1-20 | 1-25 | 1-30 | |
| | 5 | O | X | X | X | X | X | X | |
| Copper Sulphate | 15 | O | O | X | X | X | X | X | |
| 20% solution | 30 | O | O | O | O | X | X | X | |
| | 45 | O | O | O | O | O | X | X | |
| Fungicide | | 1-10 | 1-20 | 1-30 | 1-40 | 1-50 | | | |
| | 5 | O | X | X | X | X | | | $\frac{\frac{10}{5}+\frac{30}{20}}{2}=1.75$ |
| Ammoniacal | 15 | O | X | X | X | X | | | |
| Copper Carbonate | 30 | O | O | X | X | X | | | |
| 100x standard | 45 | O | O | O | X | X | | | |
| | | 1-1 | 1-5 | 1-10 | 1-15 | 1-20 | | | |
| Neutral Copper | 5 | O | X | X | X | X | | | $\frac{\frac{1}{5}+\frac{10}{25}}{2}=.30$ |
| Acetate in | 15 | O | O | X | X | X | | | |
| Saturated | 30 | O | O | O | X | X | | | |
| Solution | 45 | O | O | O | X | X | | | |

The coefficient shown above are lower with E. parasitica than with G. rufomaculans. In the case of the Ammoniacal copper carbonate the coefficient is 8, with E. parasitica it is 1.75. G. rufomaculans used as the test organism with neutral copper acetate gives a coefficient of .7 but with E. parasitica the figure is .80. When the increased strength of the copper sulphate standard (from 10% to 20%) is taken into consideration the discrepancy is wholly eliminated and it is seen that a coefficient is equivalent to a coefficient of .7 with a 10% solution. Yet in spite of this, repeated trials with a copper sulphate solution of 10% showed conclusively that it was not sufficiently strong to kill the spores even at a 1-1 dilution which was the strongest available under the conditions of the method of procedure used. These facts point to the conclusion that neutral copper acetate is more toxic to the spores of E. parasitica than is copper sulphate.

The coefficients that have been determined in this paper represent a general comparison of the various mixtures of lime sulphur and of the two copper compounds used, with a copper sulphate solution of a standard strength. The figure representing the coefficient has no value except for comparison. The coefficient must be carefully interpreted because of the unequal proportion in which the dilutions of the standard solution and the fungicide are made up. For example, the experiments with lime sulphur show a difference in dilution of 20 when dilutions are 1-220, 1-240, etc. The killing point of lime sulphur therefore is determined with an accuracy of $\frac{20}{220}$ or $\frac{1}{11}$. On the other hand the dilutions of copper sulphate are 1-5, 1-10, etc. In this the point that permits growth is one-half weaker than the dilution that kills. The rate of increase in dilutions should be as near the same with both trial fungicide and standard solution as possible. It would be desirable to increase the dilution of copper sulphate by one instead of five and so determine more accurately the killing point with this material. The mathematical calculation of the coefficient would thus be more exact.

The method here recorded has proved less satisfactory for the lime sulphur mixture than for the copper compounds. In some cases the results obtained with lime sulphur showed slight variation. This was especially true when very dilute solutions were used such as was necessary when E. parasitica was the test organism. In such cases many trials were made and the average taken. The copper solutions did not show such variations.

Of the organism used G. rufomaculans seemed to be best suited for a standard although the possibilities of biological strains is an important drawback in its use. The variability in spore resistance exhibited by E. parasitica, especially with lime sulphur, makes it of little value as a test

organism. It is quite probable that forms other than those which have been used can be substituted to advantage, and it is to be hoped that a completely satisfactory standard organism can be determined.

## SUMMARY.

1. A method for the laboratory determination of the copper sulphate coefficient of fungicides has been devised.

2. This method has been formulated to determine the fungicidal value of various fungicides in terms of a standard copper sulphate solution. It is based upon the method of Anderson and McClintic which determines the bacterial efficiency of disinfectants by comparing them with a phenol solution of standard strength.

3. The fungicides tested have been several commercial mixtures of lime sulphur, ammoniacal copper carbonate and neutral copper acetate.

4. The organisms used for the tests are Glomerella rufomaculans (Berk) S & S., and Endothia parasitica (Murrill) Anderson.

5. The coefficients found represent the relative efficiency of the fungicides tested as compared with copper sulphate solution at a standard strength.

This work was done at the State College of N. C. Botanical Laboratory, under the direction of H. R. Fulton.

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# SYSTEMATIC BOTANY.

W. J. BEAL.

Many years ago, I gave living grasses to several colleges. One professor of agriculture made some experiments and wrote reports. He afterwards told me that he had made a mistake or had taken one grass for the other.

After his death, I bought for the herbarium about 2,500 fungi that G. H. Hicks had collected. He had large numbers of single leaves or parts of leaves as hosts for some fungi, quantities of parts of leaves of many species of Carex, apparently all of them not correctly named—he was mistaken in supposing that all were the hosts of Puccinia Caricis. I threw all that lot away as worthless.

The student of parasitic fungi must know for sure the names of the hosts. In many cases this knowledge means a lot of systematic botany. The person who looks after the lists of weeds and grasses, trees and shrubs for an agricultural college is helpless without systematic botany. The same is true of the student of ecology. I could give the name of a professor who once showed me specimens which he had collected and written about, some of which he named wrong.

In another case a student had written a thesis for a second degree on Bermuda grass, while his plant was *Sisyrinchium Bermudianum* (?), a plant of the Iris family, a horrid blunder. His committee did not consult a botanist.

I presume other botanists have adopted a scheme which I have followed in collecting parasitic fungi, viz., in starting out to collect have one or more lists of hosts to look for and then look for the parasite.

In this short paper I have said enough to show the mistakes in ignoring the ability to identify seed-plants with certainty.

Amherst, Mass.

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19th Mich. Acad. Sci. Rept., 1917.

# THE PHYLOGENY OF THE GRASSES.*

BY ERNST A. BESSEY.

It is a truism that one often "cannot see the forest for trees." This applies too often in systematic botany. The now-a-days often despised but none the less indispensable specialist in the various genera and families of plants frequently seems to lack the necessary perspective which would enable him to group his species and genera to correspond to some more general scheme of phylogeny. The modern systematist, to be sure, believes in evolution and strives to arrange his species in diverging series in accordance with the probable evolutionary sequences in the group. But without the perspective the group may be "stood on its head," as it were, without interrupting the evolutionary continuity within the group. Yet such a treatment interferes greatly with the linking together of families, orders, and higher groups into an orderly system. Sometimes an arrangement adopted before the advent of evolutionary ideas is retained, long after all botanists have become evolutionists.

Such then, has been the fate of the grasses (Family Poaceae). The present division into twelve to fifteen tribes was, as it were, crystallized by Bentham and Hooker in their invaluable work "Genera Plantarum," a work too often neglected in favor of the perhaps more easily read "Natuerliche Pflanzenfamilien" of Engler and Prantl. Hackel, the great Austrian grass specialist, who worked over this family for the last mentioned work, followed in the main, the tribal divisions and arrangement of Bentham and Hooker, with some improvements. It is essentially this arrangement that the eminent American authority on grasses, A. S. Hitchcock, follows in his treatment of grasses in the New Gray's Manual and that Nash follows in Britton and Brown's Illustrated Flora.

In the foregoing arrangements the first tribe is the Maydeae, followed by the Andropogoneae, Paniceae, Oryzeae, Phalarideae, Agrostideae, Aveneae, Chlorideae (not mentioning several smaller, mostly tropical tribes) and winding up with the Festuceae, Hordeae and Bambuseae. It is not at all impossible to erect a phylogenetic tree in which the Maydeae, Andropogoneae and Paniceae shall be the trunk and basal branches, with the Festuceae, Hordeae and Bambuseae as the expression of the

19th Mich. Acad. Sci. Rept., 1917.

*The reader is referred to the brief popular paper on this same subject by W. H. Lamb, based, in its main features, like the present paper, on the unpublished work of Charles E. Bessey.

highest development of the group. In and of itself this arrangement is perhaps almost as logical as any other. The difficulty is that it emphasizes the *differences* between the grasses and other groups and makes this family stand far removed from and without any good connections with other groups. As a result most systematists have been led to look upon the grasses either as standing very low in the Monocotyledoneae or perhaps even as having arisen independently from some ancestral Protoangiosperm.

Hackel made a careful study of the structure of the grass spikelet and flower and came to certain conclusions as to the homology of their parts. According to him the flower is strictly achlamydeous, enclosed between two bracts, the palea and lemma (using Hitchcock's terminology), one or several such units being arranged either terminally or laterally (and then alternately) on the rachilla, the whole being subtended by two glumes and being known as the spikelet. The lodicules are looked upon by Hackel as special organs to be considered as bractlets and not homologous to any part of the perianth. The pistil in his opinion is monocarpellary, with a single basal ovule. The stamens are usually in one whorl of three, rarely in two such whorls.

This idea of the flower was not satisfactory and other botanists began to look upon the lodicules as representing part of the perianth, most likely two petals because of their position alternating with the outer whorl of stamens. Miss E. R. Walker, working in Nebraska, demonstrated by following its development from its first inception that the grass pistil is really tricarpellary with usually two stigmas and with the ovule attached to the third carpel which bears no stigma. In rice, various bamboos and a few other genera all three carpels have well developed stigmas. Julius Schuster, working under the direction of Goebel on some peculiar tropical grasses showed that the lodicules (which are usually two in number, but three in some bamboos) represent true petals and that the palea represents two sepals, mostly united (but then with the keels of each forming the two keels characteristic of the palea) rarely separate, and in some genera three in number. The usually missing sepal is the one next to the subtending lemma, the missing petal being next to the palea (two united sepals).

Thus we see that the ordinary grass flower consists of a tricarpellary pistil, one or two whorls of three stamens each, an incomplete whorl of petals (lodicules) and an incomplete whorl of sepals (united to form the palea), this flower being seated in the axil of a single bract (the lemma). The type of flower just described will be recognized by botanists who know the Monocotyledoneae as being of the general Lily type. In the Lilies (using this term in the widest sense to include the whole order

Liliales) we find a tricarpellary pistil (usually trilocular, sometimes unilocular) mostly multiovulate, sometimes parviovulate, two (rarely one) whorls of three stamens each, and three petals and three sepals, the whole flower usually axillary to a bract.

If we study the different genera of the Liliales further we find that there is a marked tendency toward a spicate arrangement of the flowers, in which the flowers are reduced in size in proportion to their number and crowding, the subtending bracts being proportionally larger with reference to the flower. In certain families and genera (e. g. species of Tillandsia) these bracts are two ranked and the small flowers are entirely concealed by them except at anthesis when they gape apart a little and allow stamens and stigmas and part of the perianth to appear. Spikes of this sort are frequent in the Bromeliaceae and resemble enormous spikelets of Eragrostis. In some of these plants the lowermost bracts subtend only imperfectly developed or rudimentary flowers, then corresponding perhaps to the two outer glumes of the grass spikelets.

The occurrence in the Liliales of such spikelet-like structures made up of two ranked bracts each subtending a small flower which in itself is of the general Lily type (and sometimes with certain members missing) would seem to indicate that the most primitive grasses must be sought in those tribes in which these structures are most fully carried out. For this reason my father, C. E. Bessey, long ago decided that the Bamboos (Bambuseae) as a whole are the most primitive of the grass tribes. Not all of the many genera of this tribe are equally primitive, for some show a great degree of specialization. Indeed within this tribe there seems to be less uniformity in floral structures than in any other grass tribe, the vegetative structures, on the other hand, being remarkably uniform. The more primitive bamboos possess spikelets with a very long rachilla bearing a large number of florets. Sometimes several such rachillae arise from one pair of glumes as sometimes happens in some of the Bromeliads. The flowers (in some genera) possess three stigmas, two whorls of three stamens each, three large lodicules which are even petal-like in appearance. The palea, however, although sometimes deeply cleft is united and the third sepal is missing. The pistil does not always develop into the caryopsis found in the other grass tribes, but in some cases is partially fleshy externally, forming in fact a sort of drupe, and in others forms a nut, although mostly even in this tribe the typical caryopsis is found.

Thus, viewing the grasses from the standpoint of the Monocotyledoneae as a whole it seems more reasonable to place the Bambuseae at the base instead of at the apex of the family. (Fig. 12.) This emphasizes the points of similarity and relationship with other groups of plants and

looks upon the grasses as derived from the great Lily complex from which have doubtless arisen also the Aroids, and Palms, among the forms with reduced crowded flowers, and the Amaryllises, Irides, Cannas and Orchids among the large-flowered forms with inferior ovary.

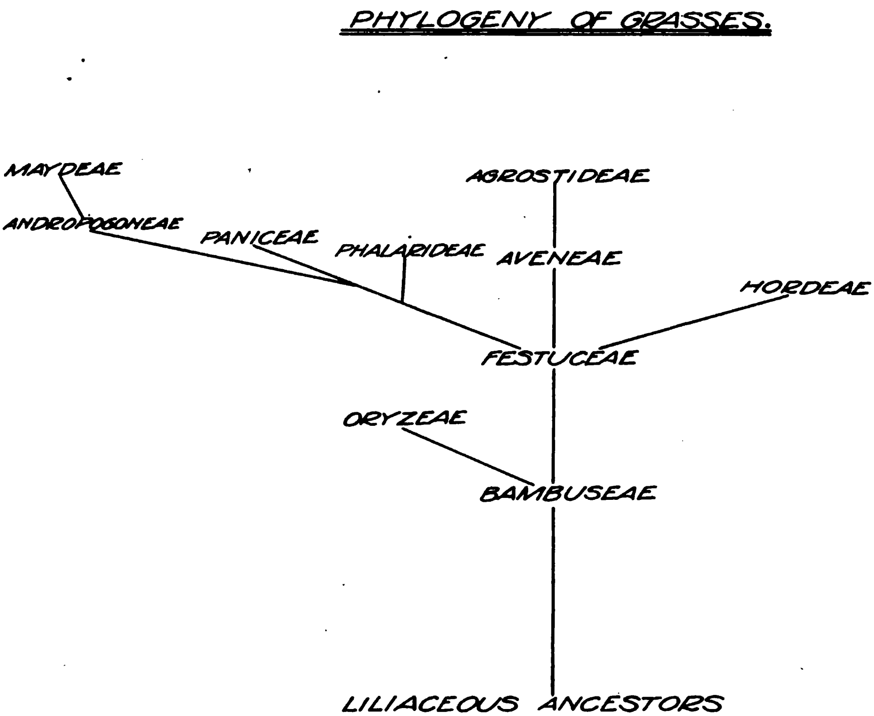


Figure 12. Chart illustrating the hypothetical phylogeny of the grasses.

Putting the tribe Bambuseae first it is clear that the tribe most nearly related as far as spikelet structures is concerned, is the Festuceae, although this tribe as well as all the other grass tribes (Oryzeae excepted) possesses a somewhat reduced floral structure. There is but one whorl of stamens, the fruit is always a caryopsis and there are but two lodicules. In the Festuceae the chief characters are the many-flowered spikelets in typical or reduced panicles with the glumes not exceeding the lemmas. Within the tribe we find all sorts of modifications, such as larger or smaller numbers of flowers; awned or awnless, keeled or rounded, many-ribbed or few-ribbed glumes or lemmas, etc.

Closely allied to the Festuceae and to be regarded as an offshoot from the tribe stand the Hordeae, in which the spikelets are similar but the panicles are reduced to a zig-zag rachis, forming a head such as we know for wheat, rye, etc.

There are some Festuceae in which the number of florets is reduced to but few and the glumes extend nearly out to the tip of the topmost lemma. These indicate to us how the Aveneae probably arose from the Festuceae. These possess regularly only a few florets, two to three, sometimes only one or two, and the glumes are so large as to include them almost completely. The reduction in the number of florets has been from the apex downward. It is so pronounced in a few Aveneae that we find a very good series of transition forms to the Agrostideae. In this tribe there is but a single floret, either terminal on the rachilla or lateral, with the apical portion of the rachilla running up by the floret but not bearing another. It is the presence of this rudiment of the originally longer rachilla that makes it probable that this tribe has arisen from the Aveneae by the gradual apical suppression of florets. Within the tribe some significant modifications are worthy of mention. On the one hand the glumes may become still more pronounced and even somewhat hardened, the lemma and palea being correspondingly more membranaceous, or the latter may become indurated, as in Stipa and Milium, and the glumes thin and in some cases reduced or even lacking. The palea may be reduced or even almost disappear as in some species of Agrostis. Another tendency begins to show itself, being a natural corollary of the one-flowered condition of the spikelet. In all the tribes hitherto mentioned the rachilla dehisces just above the two glumes and where it bears several flowers it very frequently breaks into as many pieces as there are flowers. Many of the Agrostideae still retain this habit but in some genera the spikelet drops off as a whole, the point of dehiscence being below instead of above the two glumes.

The tribe Phalarideae shows an evolutionary tendency along a different direction. The shortening of the rachilla does not occur as in the Aveneae by the reduction and disappearance of the apical florets but of the basal ones, so that the apical floret is the largest. It is, indeed, the only functional one in most genera of the tribe, the two other (basal) florets being either staminate or represented only by their lemmas which may be reduced to tiny scales. It can hardly be doubted that this tribe is also an offshoot of the Festuceae.

Mention must be made of the tribe Chlorideae as it seems to be a decidedly unnatural group. Its chief characters are the arrangement of the spikelets (usually in two rows) along the under side of the more or less horizontal racemes of the inflorescences, the rachilla in all cases being detached above the glumes. In studying the structure of the spikelets themselves it is apparent that those of Eleusine are an almost perfect match for Poa in the Festuceae, while other genera have spikelets typical of the Aveneae or Agrostideae. It seems to me more reasonable to dis-

tribute these genera to their three tribes and abolish the Chlorideae altogether. It must be remembered that if this principle were carried throughout the whole family the genera Paspalum and Syntherisma would have to be removed from the Paniceae and placed in a separate tribe, a procedure absolutely unthinkable.

Of the remaining important tribes the Paniceae may be given first mention. The spikelet here falls away as a whole. The spikelets are mostly arranged in panicles (excepting Paspalum, Syntherisma, etc.). The spikelet has one perfect flower, terminal to the rachilla with strongly indurated lemma and palea, and one basal flower which is mostly either staminate or represented only by an indurated lemma with or without a palea. The two glumes are mostly membranaceous. We at once think of the tendency towards reduction in the florets from the base upwards exhibited by the Phalarideae and cannot but believe that the two tribes may have had a common origin somewhere in the Festuceae, paralleling some of the Agrostideae in such features as reduction of perfect florets to one, induration of lemma and palea, dehiscence of rachilla below the glumes, etc.

The other tendency mentioned as shown by some genera of the Agrostideae, that of having the glumes indurated and the lemma and palea thin is paralleled by the Andropogoneae, a group distinct from but clearly of common origin with the Paniceae and Phalarideae because of the well developed terminal and often greatly reduced basal floret in each spikelet.

The Maydeae are obviously nothing but Andropogoneae modified by having the monœcious or diœcious spikelets set apart in different parts of the same inflorescence or in distinct inflorescences. In vegetative structure as well as in that of the grain the two tribes are practically indistinguishable. Indeed, the grain structure of the Paniceae differs but slightly from that of these tribes.

The only important tribe not mentioned is the Oryzeae. The forms ordinarily included in this tribe seem to be rather heterogeneous so that it is well within the bounds of possibility that some of them should be segregated into other groups. Taking the better known forms into consideration we find that the flowers have usually three stigmas, more often two whorls of three stamens each instead of the one whorl found in most of the grass tribes, but one flower to a spikelet, the lemma and palea usually quite similar and somewhat indurated, the glumes membranaceous, often small or almost lacking. The tristigmatic pistil and the two whorls of stamens show a degree of primitiveness shown only by the Bambuseae. The structure of the caryopsis differs in many respects from that of the other tribes so that it seems most reasonable to

derive the Oryzeae from some of the more highly developed Bambuseae that have the spikelets reduced to one floret.

To summarize briefly: The Grass flower is of the Lily type, mostly however, with but one whorl of stamens, and with one petal and one sepal missing. The spikelet is homologous to the two-ranked spikes of flowers found in some Liliales, e. g., some Bromeliaceae, the lemmas being homologous to the subtending bracts of such a spike. This being so, those grasses whose spikelets and flowers most nearly resemble such liliaceous spikes and flowers must be considered as representing the most primitive grasses. Such we find among the Bambuseae. From this tribe arose the Festuceae and Oryzeae. The former gave rise to the Hordeae and Aveneae, the latter leading to the Agrostideae. The Phalarideae, Paniceae and Andropogoneae probably arose from a common root from the Festuceae, the Andropogoneae giving rise to the Maydeae.

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*Only such titles are listed here as were mentioned in the text.

# NEW SPECIES AND VARIETIES FROM MICHIGAN.

BY OLIVER ATKINS FARWELL.

## CYPERACEÆ.

SCIRPUS OCCIDENTALIS (Watson) Chase, variety CONGESTUS, N. var.

Spikelets aggregated into a sessile glomerule or if peduncles are present these are so short that they are hidden by the spikelets. Marl lake, No. 4294, July 9, 1916, and No. 4876, August 18, 1916. Bears the same relation to the species that variety *confertus* does to *S. rubrotinctus*. Not as common as the species.

CAREX CANESCENS Lin. var. HETEROSTACHYA, N. var.

In this form of the species the terminal spike is entirely staminate. Collected on the Keweenaw Peninsula many years ago.

## JUNCACEÆ.

JUNCUS BUFONIUS Lin. var. RANARIUS, N. var.

*Juncus ranarius* Song. et Perrier in Billot Annot. Fl. France et Allem. 192, 1859 not Nees, 1847. (?)

Sheathes of the lowest leaves dark red, the petals acute not awl pointed, about the length of the capsule and shorter by about a millimeter than the awl pointed sepals. In this plant the flowers are single and remote as in the species but the petals are shorter than the sepals and not awl pointed, resembling in these characters the var. *halophilus*. River Rouge, No. 4842, July 21, 1916.

## ORCHIDACEÆ.

CORALLORHIZA MACULATA Raf. var. INTERMEDIA, N. var.

Whole plant purplish yellow; lip white with two or three large, very pale purplish spots; no spots on the other petals or sepals. Copper Harbor, Keweenaw Peninsula, No. 4008, July 8, 1915. Exactly intermediate between the species and the var. *flavida* (Peck) Cockrl. in color and in spots which are found only on the lip and are fewer, larger, and paler than in the species. The species is common; and the var. *flavida* also is found at Copper Harbor, No. 4002, July 8, 1915.

19th Mich. Acad. Sci. Rept., 1917.

## CRUCIFERACEÆ.

ARABIS LÆVIGATA (Muhl.) Poir. var. HETEROPHYLLA, N. var.

*Arabis heterophylla* Nutt.; T. & G. Fl. N. Amer. I, 81, 1838.(?)

Lower part of stem, including leaves, and the rosette leaves pubescent with short, spreading hairs, elsewhere glabrous and glaucous. Rosette leaves and lowermost stem leaves lyrately pinnatifid gradually passing to obovate and laciniate, thence to ovate, ovate-, oblong-, and linear-lanceolate and dentate or entire. The rosette leaves and those on the lower part of the stem are purplish underneath. Flowers erect on erect or slightly spreading pedicels; petals white, six or seven millimeters long, from one-half as long again to twice as long as the sepals; pods spreading or recurved five to seven centimeters long by one and three-quarters to two millimeters wide with a short, stout style not over a millimeter long or sessile stigma. Zoological Park near Royal Oak No. 4210, July 13, 1916.

This plant cannot be typical *A. laevigata* as that is always described as entirely glabrous and glaucous while the lower parts of this plant are pubescent. The longest leaves are on the basal part of the stem and are about five centimeters long; the shortest are the uppermost and are six or seven millimeters. It may be the *A. heterophylla* of Nuttall which was described as with hirsute radical leaves.

## SAXIFRAGACEÆ.

TIARELLA CORDIFOLIA Lin. var. BRACTEATA, N. var.

Scape bearing on the middle section a petioled leaf somewhat similar to the basal but much reduced in size; petiole three millimeters to two centimeters long and the ovate, three-lobed blade from one-half to two centimeters in length and breadth. Near Disco, Macomb Co., No. 4153, May 25, 1916.

## CALCARATACEÆ.

VIOLA CANADENSIS Lin. var. PUBENS, N. var.

More or less densely and almost canescently pubescent throughout with short, spreading hairs. Otherwise like the specific type which is here considered to be the common glabrous form. Near Disco in Macomb Co., No. 4155, May 25, 1916.

VIOLA CONSPERSA Reichb. var. MASONII, N. var.

Flowers pure white. Has the appearance of V. striata but can be readily distinguished by the entire sepals. Near Utica, No. 4163, June 6, 1916. Named for Mr. E. W. Mason of Lapeer who first observed it near Utica and who called my attention to it.

VIOLA ROSTRATA Ait. var. ELONGATA, N. var.

Spur 15 to 18 millimeters long; sepals narrow, one millimeter or less wide. Near Utica, No. 4166, June 16, 1916. Differs from the species in having a much longer spur and much narrower sepals.

## LABIATACEÆ.

SCUTELLARIA LATERIFLORA Lin. var. ALBIFLORA, N. Var.

Flowers white. Grosse Isle, No. 4385, August 20, 1916.

## RINGENTACEÆ.

MIMULUS ALATUS Ait. var. CHANDLERI, N. Var.

Flowers pale lavender to white. Collected by Mr. B. F. Chandler of Detroit, at Gawklers Point in August, 1916.

MIMULUS RINGENS Lin. var. CONGESTA, N. Var.

Peduncles shorter than their subtending leaves, Grosse Isle, No. 4391, August 20, 1916. In the specific type the peduncles are longer than their subtending leaves on the upper parts of the plant forming a broad and open inflorescence. In this variety the peduncles are much shorter, forming a narrow, close inflorescence.

VERONICA ANAGALLIS-AQUATICA Lin. var. GLANDULOSA, N. Var.

Stem more or less glandular pubescent. Whole plant smaller and less succulent than in the specific type. Zoo Park, near Royal Oak, No. 4328, July 18, 1916.

PEDICULARIS LANCEOLATA Mx. Var. HIRSUTA, N. Var.

Stems and branches hirsute. In the typical plant the stems and branches are glabrous. On Parkedale Farm, No. 4418½, Sept. 8, 1916; No. 4016, Sept. 8, 1915; No. 4134, October 15, 1915, from Detroit.

## COMPOSITACEÆ.

ASTER NOVÆ-ANGLIÆ Lin. var. MONOCEPHALA, N. Var.

Stem, simple, strict, ending in a single head. Belle Isle and other places in Detroit.

HELIOPSIS SCABRA Dun. var. INTERMEDIA, N. Var.

Stems glabrous; leaves firm and harshly scabrous as in the species. Near Rochester, No. 4330, July 15, 1916, and No. 4349, August 12, 1916, near Farmington. The species has a very scabrous stem as well as leaves.

LACTUCA CANADENSIS Lin. var. ALBOCÆRULEA, N. Var.

Flowers pale blue to white. Bloomfield, No. 4394, August 22, 1916.

Detroit, Mich.

# RARE OR INTERESTING PLANTS IN MICHIGAN.

BY O. A. FARWELL.

## POLYPODIACEÆ.

FILIX CRISTATA (Lin.) Farwell var. CLINTONIANA (D. C. E.) Farwell.

A rare fern. Only three stations are given for it by Beal in the Michigan Flora. It is to be found in cool, moist woods near Utica. No. 4179, June 6, 1916.

## SPARGANIACEÆ.

SPARGANIUM SIMPLEX Hudson.

Several species have been segregated from the S. simplex of our earlier manuals. I have not seen anything answering to the *S. simplex* Hudson as now understood. *S. Americanum* Nutt. and *S. diversifolium* Græbner should replace the S. simplex of Beal's Michigan Flora.

SPARGANIUM AMERICANUM, Nutt.

4248, June 29, '16, Cass Lake; 812, Aug. 25, '90, Keweenaw County; 812a, July 24, '10, Rochester.

SPARGANIUM DIVERSIFOLIUM Græbner.

Borders of Cass Lake: No. 219, June 16, 1885.

SPARGANIUM DIVERSIFOLIUM var. ACAULE (Beebe) F. & E.

2106, Aug. 15, '09, Rochester; 219a, June 16, '85, Keweenaw; 4249, June 29, 1916, Cass Lake.

## FLUVIALACEÆ.

POTAMOGETON AMERICANUS C. & S.

Said to be a rare species in Michigan. It is to be found in a slip at the Great Engineering Works, at River Rouge. No. 4840, July 21, 1916.

## JUNCAGINACEÆ.

TRIGLOCHIN MARITIMUM Lin. Sp. Pl. I, 339, 1753.

*Triglochin maritimum* Lin. var. *exangulare* Reichenb. Ic. Fl. Germ. VII, 28, t. L*11* fig. 93, 1845.

TRIGLOCHIN MARITIMUM Lin. var. SEXANGULARE Reichenb. l.c. fig. 92.

*Triglochin elatum* Nutt. Gen. I, 287, 1818.

*Triglochin maritimum* Lin. var. *elatum* (Nutt.) A. Gr. Man. 487, 1856.

There are two forms of the Spike Grass; one with ovoid fruit without a neck at the apex and with rounded carpels; the other has oblong fruit contracted into a neck at the apex and the carpels have depressed backs. The former is typical of the species and the edges of the carpels are not sharply acute; in the latter which is characteristic of the variety the carpels are sharply acute or winged. Reichenbach's varietal name is older by seven years than that of Gray and should be adopted. Both the species and the variety were accredited to Michigan (Great Lakes region) but all the Michigan material which has passed under my observation is of the variety. The cross section of the fruit of the species is circular in outline while that of the variety is strongly and regularly angular with concave edges between the angles. Marl lake, No. 4292, July 9, 1916.

## ALISMATACEÆ.

SAGITTARIA LATIFOLIA Willd.

In most of its forms this species is common throughout the state. At Marl lake a form was found that had narrowly linear blades and lobes which unquestionably is the *forma gracilis* (Ph.) Robinson. Not before reported from the state. No. 4362, Aug. 18, 1916.

## GRAMINACEÆ.

ZIZANIA AQUATICA Lin.

There are two species of Water Oats or Indian Rice in Michigan. One is a tall, coarse plant with broad leaves and is the *Z. palustris* Lin. The other is a slender, small plant with very narrow leaves and is the *Z. aquatica* Lin. They are seldom found growing together but when they are so found they are readily distinguished, and do not seem to intergrade. Marl lake No. 4372, Aug. 18, 1916, and No. 2115 from Huron River near Geddes, Aug. 21, 1909, are *Z. aquatica* Lin. No. 1297, August 12, 1892, from Belle Isle; No. 1297a, August 14, 1909, from Grosse Isle; and No. 1297b, from Huron River near Geddes; are *Z. palustris* Lin.

SPARTINA PATENS Var. JUNCEA (Mx.) A. S. H. No. 4111, Sept. 23, 1915.

An Atlantic salt-water-marsh plant that has become established in the salt marshes at Oakwood.

## CYPERACEÆ.

TRICHOPHYLLUM ROSTELLATUM (Torr.) Farwell.

Said to be rare in Michigan. The tough, sterile stems recline upon the earth and when well rooted at the proliferous apex are very liable to trip up the unwary traveler. Marl lake, No. 4802, July 9, 1916.

ERIOPHORUM CYPERINUM Lin. var. PELIUM (Fernald), N. Comb.

*Scirpus cyperinus* (Lin.) Kunth var. *pelius* Fernald, Rhodora VIII, 164, 1906.

In swamps throughout the state; infrequent in southern Michigan but common in the Upper Peninsula. Marl lake, No. 4858, August 18, 1916.

TRIODON ALBUS (Lin.), n. comb.

*Schoenus albus* Lin. Sp. Pl. 44, 1758.

TRIODON ALBUS (Lin.) var. MACER (Clarke), N. comb.

*Rhynchospora alba* (Lin.) Vahl. var. *macra* Clarke in Britt. Trans. N. Y. Acad. Sci. XI, 88, 1892.

The variety *macer* has not heretofore been reported from Michigan, in so far as I am aware. It is a tall, coarse plant with a corymb 2-4 cm. broad. Marl lake, No. 4875, August 18, 1916. Bloomfield Center, No. 4899, August 22, 1916.

MARISCUS MARISCOIDES (Torrey) O. K. Said to be infrequent. Marl lake, No. 4808, July 9, 1916, and No. 4864, August 18, 1916.

SCLERIA VERTICILLATA Muhl.

A rare species in Michigan. I have seen it only on marl beds. Marl lake, No. 4867, August 18, 1916.

CAREX DIANDRA Schrank var. RAMOSA (Boot) Fernald.

Apparently this form is more common in Michigan than the species, at least in the southeastern section. Marl lake, No. 4812, July 9, 1916.

CAREX CHORDORHIZA Lin. f.

This species, recorded as rare in Michigan, is quite common in an extensive peat bog in the vicinity of Pontiac, No. 4228, June 18, 1916.

CAREX POLYGAMA Schk. var. HETEROSTACHYA (Anderss.), N. Comb.

*Carex Buxbaumii* Wahl. var. *heterostachya* Anderss. Cyper. Scand. 39, 1849.

In this form the terminal spike is entirely staminate. Quite common in places. Algonac, No. 4230, June 22, 1916; Detroit, No. 2034, July 14, 1907.

Carex deflexa Hornem.

While on a botanical excursion through the fields in the vicinity of Algonac on June 22, 1916, in search of some early flowering Bartonia Virginica that had been found there the preceding autumn, a small area of ground was discovered which was fairly well covered with a small, dark green Carex that on close examination proved to my great surprise and delight to be the rare *Carex deflexa*. It was more than a score of years since I had discovered this species on the Keweenaw Peninsula and it had not been seen in the interim and, so far as I am aware, it had not been reported by others, so that these two places are the only known localities for the species in Michigan. The field was low, moist ground only a few feet above the level of Lake St. Clair. The Carex was growing in moss that covered the low knolls or elevations as well as the hollows. The typical form, No. 4226½, is a low plant with leaves not over 20 cm. long and erect, the culms being not over one-half that length and strongly curved. Another and more common form, No. 4226, is the variety *Deanei* Bailey which is more lax and has much longer leaves equalled or exceeded by the culms which are more slender and less curved than in the species. The station near Algonac is close to the southern limits of the range of the species.

Carex limosa Lin.

This is a very slender sedge that may be looked for in peat bogs. I have not found it in other habitats. It cannot be classed as a common plant in Michigan. Bloomfield, No. 4198, June 15, 1916.

Carex laxiculmis Schw.

A rare sedge in moist woods. The large patches of broad, glaucous, basal leaves at once suggests *C. granularis* or its variety *Haleana* but the culms and spikes readily show it to be not that species. Vicinity of Palmer Park, No. 4279, July 2, 1916.

Carex Pseudo-Cyperus Lin.

A rare sedge in Michigan. I first made its acquaintance last year, 1916, at Cass Lake, where it was not at all plentiful. No. 4247, June 19.

Carex Pseudo-Cyperus Lin. var. comosa Boott.

Larger and coarser than the species with thicker spikes, more loosely flowered and perigynia with a longer beak, the teeth of which are more spreading; the perigynia usually are horizontally spreading. Generally considered as a distinct species under the name of *Carex comosa* Boott. There are intermediate forms, however, with the perigynia strongly reflexed and it might better be considered as a variety of *C. Pseudo-*

*Cyperus* than as a separate species. Cass Lake, No. 4246, July 29, 1916; Tacoma, No. 4266, July 2, 1916.

## JUNCACEÆ.

Juncus pelocarpus, E. Meyer.

One of the rarer species in Michigan. May be proliferous. Marl Lake, No. 4365, August 13, 1916.

## LILIACEÆ.

Quamasia esculenta (Nutt.) Raf.

Frequent on the banks of the Huron near Rockwood, No. 4149, May 21, 1916. Nuttall was the first to discover and name this species. The original habitat or type locality is "near the confluence of Huron River and Lake Erie;" the station at Rockwood, the only one at present known which might come within the limits of the type locality, may be the identical place where Nuttall originally found the species. Rafinesque established the genus Quamasia in 1818, naming one species, *Q. esculenta*, which by many present day botanists is considered to be the western *Q. Quamash* (Pursh.) Coville. I have not seen Rafinesque's publication, but in his Medical Flora II, 255, 1830, his concept of his *Quamasia esculenta* is exactly that of Nuttall's, i. e., it includes both the eastern *Camassia Fraseri* Torr. and the western *C. esculenta* Lindley. If the above is the proper interpretation to be applied to Rafinesque's *Q. esculenta*, then it has been erroneously referred to the western species. Nuttall's species (Fraser's Catalogue, 1813, and Genera I, 219, 1818) was based on plants collected by Nuttall himself in 1810 at the type locality above cited; he also included the western plant under the impression that it was the same species. Rafinesque's name, if based upon Nuttall's, as is probably the case, must of course belong to the eastern species.

Aletris farinosa Lin.

A rare plant in Michigan. Prefers dry, sandy soil. Vicinity of Marl Lake, No. 4309, July 9, 1916.

Smilax rotundifolia Lin. var. caduca (Lin.) A. Gr. in Darl. Fl. Cest. 319, 1853.

*S. caduca* Lin. Sp. 1030, 1753.

*S. quadrangularis* Muhl. in Willd. Sp. Pl. IV 775, 1806.

*S. rotundifolia* Lin. var. *quadrangularis* (Muhl.) Darby, Bot. So. States 518, 1855.

Usually rather low and often with very stout, flat spines, colored at the tips, Algonac, No. 3156, June 22, 1916.

## SALICACEÆ.

SALIX FRAGILIS Lin.

River banks at Stoney Creek. An escape from cultivation. Seems to have taken the place of S. alba in this vicinity. No. 4152½, May 25, 1916.

SALIX PEDICELLARIS Pursh. var. HYPERGLAUCA Fernald.

A very attractive bog willow. Frequent in bogs and wet meadows. Has passed in our manuals for the European *S. myrtilloides*. Bloomfield, No. 4198, June 15, 1916.

## ARISTOLOCHIACEÆ.

ASARUM REFLEXUM Bicknell var. AMBIGUUM Bicknell.

Woods in Macomb Co., near Disco, No. 4156, May 25, 1916.

*A. Canadense* Lin. is credited to Michigan but such plants as I have seen are referable to this species or to *A. acuminatum* (Ash) Bicknell.

## PERSICARIACEÆ.

POLYGONUM DUMETORUM Lin.

This species probably has been confused with *P. scandens* Lin. and is more frequent in the state than has been supposed. Rochester, No. 4417, Sept. 3, 1916.

## ALSINACEÆ.

SCLERANTHUS ANNUUS Lin.

Fields at Detroit and Wyandotte. Reported by Dr. McCall of the latter place as overrunning cultivated fields. No. 4314, July 11, 1916.

## CRUCIFERACEÆ.

BERTEROA INCANA (Lin.) DC.

A hoary pubescent, branching herb that is rapidly spreading and bids fair to rival the Wild Mustard as a pernicious weed. Bloomfield, No. 4188, June 15, 1916.

ARABIS LYRATA Lin. var. INTERMEDIA (DC), N. Comb.

*Arabis ambigua* DC. var. *intermedia* DC. Syst. II, 231, 1821.

*Arabis lyrata* Lin. var. *occidentalis* Wats. in A. Gray Syn. Fl. N. Amer. I, 159, 1895.

Stigma together with very short and thick style about one-third of a millimeter or less; lower one-third of stem with its leaves more or less hirsute. Has been recorded from three places, Bower's Harbor, Grand

Traverse Bay and Alpena in Beal's Michigan Flora. I have collected it from Rochester, No. 1538½, July 4, 1896, and from Macomb Co. in vicinity of Disco, No. 4158, May 25, 1916.

## HAMAMELIDACEÆ.

A few years ago Dr. Sargent described a new species of Hamamelis, *H. vernalis,* flowering, as the specific name indicates, in the spring. A search for this species in Michigan has not disclosed its presence here. But unlooked for conditions concerning *H. Virginiana* were discovered which may be of sufficient interest to others to have them placed upon record. One of the characters of *H. vernalis* is the red inner surface of the calyx lobes. In *H. Virginiana* the inner surfaces of the calyx lobes are yellow at the beginning of the flowering season, usually in September in this locality, but gradually grow darker until, at the end of the flowering period which is about the close of the year, most of them are red; all of them are red when vegetation begins in the spring; at least no calyx lobe has been discovered that was yellow on the inner surface at this time. Individual shrubs were found that had red calyx lobes from the beginning and some even had petals with the lower portion red. The parti-colored petals, however, were not numerous, nor, in all cases, were all the petals of the one flower bicolored.

## POMACEÆ.

PYRUS MELANOCARPA (Mx.) Willd.

Said to be frequent throughout the state, Bloomfield, No. 4201, June 15, 1916; Vic. Palmer Park, No. 4403, August 27, 1916.

PYRUS MELANOCARPA (Mx.) Willd. var. ATROPURPUREA (Britton), N. Comb.

*Aronia atropurpurea* Britton, Man. 517, 1901.

*Pyrus arbutifolia* var. *atropurpurea* Robinson, Rhodora X, 33, 1908.

*Pyrus arbutifolia* is credited to Michigan in Beal's Michigan Flora. One of the localities given is St. Clair Co., C. K. Dodge. Dodge's specimens in the Herbarium of Parke, Davis & Co., although distributed as *P. arbutifolia* are of this variety. It is probable that all so-called *P. arbutifolia* collected in Michigan is of this variety and the species should be excluded from the Michigan Flora. In *P. arbutifolia* the calyx lobes are very glandular and the small, ripe fruit is bright red; in *P. atropurpurea* the calyx lobes are glandless or nearly so and the fruit is much larger and purple or black. I have not seen *P. arbutifolia* from Michigan which is outside of the generally accepted range of the species. The two varieties or species have come under my observation

here where they often grow together and it seems to me that *P. atropurpurea* is but a pubescent form of *P. melanocarpa;* the size and form of the leaves and the color of the fruit are essentially the same in both; the berries of the variety are larger than those of the type, globose or occasionally oval. In the species the leaves and inflorescences are glabrous; in the variety more or less tomentose; but there are intermediate forms, and individual shrubs have some of the leaves and inflorescences tomentose while others are glabrous. It seems best, on the whole, to consider *P. atropurpurea* as not specifically distinct from *P. melanocarpa.* Bloomfield, No. 4200, June 15, 1916, and No. 4396, August 22, 1916; Vic. Palmer Park, No. 4276, July 2, 1916, and No. 4406, August 27, 1916 (some parts pubescent and others glabrous).

## GERANIACEÆ.

GERANIUM PUSILLUM Burm. f.

Banks of Detroit River in Detroit. Considered to be adventive but apparently spreading. No. 4367, July 13, 1916.

## TITHYMALACEÆ.

EUPHORBIA GLYPTOSPERMA Engelm.

Along the railroad tracks at Farmington where it is quite frequent. No. 4350, August 12, 1916.

## ZIZYPHACEÆ.

RHAMNUS CATHARTICA Lin.

A few shrubs are found scattered along a rail fence dividing pasture meadows. Probably from seed dropped by birds. No. 4392, August 22, 1916.

## SALICARIACEÆ.

LYTHRUM SALICARIA Lin.

In vicinity of Detroit. No. 4404, August 24, 1916. Probably an escape from cultivation.

## CORNICULATACEÆ.

ŒNOTHERA MURICATA Lin. var. PARVIFLORA Gates.

A narrow leaved, small flowered form of *OE. muricata.* Frequent along banks and in fields at Rochester. No. 4415½, Sept. 8, 1916; Belle Isle, Detroit, 195a, August 4, 1912; in a marl bed on Parkedale Farm, No. 3829, August 9, 1914.

Œnothera fruticosa Lin. var. phyllopus Hooker.

This is a form in which there is no distinction between stem and peduncle; the floral leaves are like those of the stem, giving to the flowers the appearance of being solitary and axillary. Freely branched. Detroit, No. 4261, June 30, 1916. Occasional and perhaps an escape from cultivation.

## CALCARATACEÆ.

Viola papilionacea Pursh. var. alba (T. & G.), N. comb.

*Viola cucullata* Ait. var. *alba* T. & G. Fl. N. Amer. I. 137, 1838.

Smooth; flowers white. Frequent in places. Near Rochester. No. 3628, May 10, 1914, and near Rockwood, No. 4144, May 21, 1916.

Viola rostrata Ait. var. phelpsiae (Fernald), N. comb.

*Violata rostrata* Ait. forma *Phelpsiae* Fernald, Rhodora XVII, 180, 1915.

Flowers white. Near Rockwood. No. 4146, May 21, 1916.

Viola pedatifida, Don.

I have seen living plants of a violet collected by Mr. E. W. Mason of Lapeer, which had palmately, many-divided leaves, the divisions of which were very long and narrowly linear or filiform. It probably belongs here, where it may be placed until further study will determine its proper disposition. This species has not before been reported from Michigan.

## MONOTROPACEÆ.

Pyrola asarifolia Mx. var. incarnata (Fisch.) Fernald.

Leaves orbicular to ovate, rounded, truncate or subcordate at base, dull, smaller than in the specific type which are of a different form also. Common in swamps at Marl Lake, No. 4184, June 11, 1916, and Nos. 4218 and 4219, June 18, 1916, from near Pontiac.

Pyrola asarifolia Mx. var. uliginosa (Torr. et Gray), N. Comb.

*Pyrola uliginosa* Torr. et Gray; Torr. Fl. N. Y. I, 453, pl. 69, 1843.

Leaves sub-orbicular to obovate, narrowed to an acute base; smaller than in the preceding variety; not common. Swamps at Marl Lake, No. 4185, July 9, 1916.

## POLEMONIACEÆ.

Gilia rubra (Lin.) Heller.

Near Farmington, No. 4357, August 12, 1916. Probably an escape from cultivation but seems to be well established. First discovered, I believe, by Mr. Gladewitz.

## LABIATACEÆ.

Ocimum basilicum Lin. var. glabratum Benth.

Collected near Cass Lake by Mr. C. Billington. Probably an escape from cultivation.

Lycopus asper Greene.

Banks of Detroit River at Wyandotte. No. 4384, August 20, 1917. Has been reported as *L. lucidus* from Port Huron by C. K. Dodge. Lower part of stems prostrate and rooting at the joints.

## RINGENTACEÆ.

Penstemon Digitalis (Sweet) Nutt.

Reported from Adrian in Beal's Michigan Flora. I have collected it on Belle Isle, No. 1916, June 20, 1905, and No. 4229 from Algonac, June 22, 1916.

## APARINACEÆ.

Galium Aparine Lin. var. eschinospermum (Wallr.), N. Comb.

*Galium Vaillantii* D. C. Fl. France IV, 263, 1805.

*Galium agreste* Wallr. Var. *echinospermum* Wallr, Sched. Crit. 59, 1822.

*Galium Aparine* Lin. var. *Vaillantii* (D. C.) Koch. Fl. germ. 330, 1837.

A smaller plant than the type with smaller leaves and fruit. On Parkedale Farm, May 30, 1914. No. 3652 and No. 3964 from Detroit, June 12, 1915.

Galium triflorum Mx. var. viridiflorum D. C.

Stems smooth. Near Marl Lake, No. 4305, July 9, 1916.

Galium Labradoricum, Wiegand.

Probably has been confused with *G. tinctorium.* It is a smaller plant with narrower and shorter, soon reflexed leaves and smaller fruit. Marl Lake, No. 4187, June 11, 1916; Bloomfield, No. 4197, June 15, 1916, and No. 4267 and 4271 at Tacoma, July 2, 1916.

## COMPOSITACEÆ.

Heliopsis helianthoides (Lin.) B. S. P. var. minor (Hook), N. Comb.

*Heliopsis laevis* Pers. var. *minor* Hook, Comp. Bot. Mag. I, 98, 1835.

*Heliopsis laevis* Pers. var. *gracilis* T. and G. Fl. N. Amer. II, 303, 1842.

Stem simple, strict, ending in a single head; leaves very thin, very slightly scabrous. Near Rochester, No. 4416, Sept, 3, 1916.

HELIANTHUS MONTICOLA Small.

A form with the lower leaves of an ovate outline and the upper leaves with a very broad clasping base. Near Rochester, No. 4881, July 15, 1916.

HELIANTHUS SCABERRIMUS Ell.

Found at River Rouge by Billington, Chandler & Gladewitz, who reported it as *H. subrhomboideus* Rydb. The involucral scales, however, are mainly obtuse, which would place it here. No. 4880, August 17, 1916. I have also collected it in Houghton Co., No. 3087, August 24, 1912.

ARTEMISIA LONGIFOLIA Nutt.

Found in considerable quantities near River Rouge. Farwell and Chandler, No. 4879, August 17, 1916.

HIERACIUM AURANTIACUM Lin.

Ballast grounds at Detroit, rare, No. 4815, July 11, 1916. Has been found also by Billington, Chandler and Gladewitz.

HIERACIUM VENOSUM Lin. var. SUBCAULESCENS, T. and G.

Near Tacoma, No. 4264, July 2, 1916.

## ADDENDA.

The plant mentioned above under *Viola pedatifida* proves to be the *V. pedata* var. *lineariloba,* DC. with very narrow or almost filiform lobes to the leaves.

PYROLA ASARIFOLIA, Mx. var. OVATA, N. name.

Since the *Pyrola incarnata* Fisch. is an Asiatic plant and a variety of the European *P. rotundifolia* Lin., the plant listed above as *P. asarifolia* Mx. var. *incarnata* should receive a new name and I propose for it the varietal name OVATA.

Parke, Davis Co., Detroit, Mich.

# FLORA OF THE DETROIT ZOOLOGICAL TRACT.

BY JOHN M. SUTTON.

The Detroit Zoological Tract consists of one hundred acres of land located partly in the village of Royal Oak, and extending west of the village limits. The south line is a half mile long running east and west, parallel to and a short distance north of the ten-mile road, as shown by the accompanying map. The northeast corner touches Woodward Avenue. The east line extends along Lafayette Avenue for about fifty rods. The north line extends west with a curve north which makes the west end of the tract about a quarter of a mile across.

There is a stand of trees near the east end of the tract on rather low land, and groves in the middle and near the west end on higher land. Three ditches run south across the park which is rolling, making some dry fields and some low, wet ground. Only part of the land has been under cultivation and of recent years most of it has been neglected.

At Dr. Bryant Walker's suggestion, a collection of the plants growing on this tract was started in the spring of 1916, trips being made once a week for this purpose. As a rule only plants observed in blossom were collected, consequently the list does not represent all of the flora. Only plants growing on this tract are included in this list with but one exception. *Grindelia squarrosa* (Pursh.) Dunal. is included because it was found growing in quantities just over the line and is so rarely met with in this part of the state.

I wish to thank Mr. C. K. Dodge of Port Huron, and Mr. C. Billington of Detroit, for examining the specimens, and Mr. Wilbur McAlpine, topographer, of Birmingham, who very kindly furnished the map.

### POLYPODIACEÆ—Fern Family.

*Pteris aquilina* L. Common Brake.

### OSMUNDACEÆ—Flowering Fern Family.

*Osmunda Claytoniana* L.
*Osmunda cinnamomea* L. Cinnamon Fern.

### OPHIOGLOSSACEÆ—Adder's Tongue Family.

*Botrychium virginianum* (L.) Sw. Rattlesnake Fern.

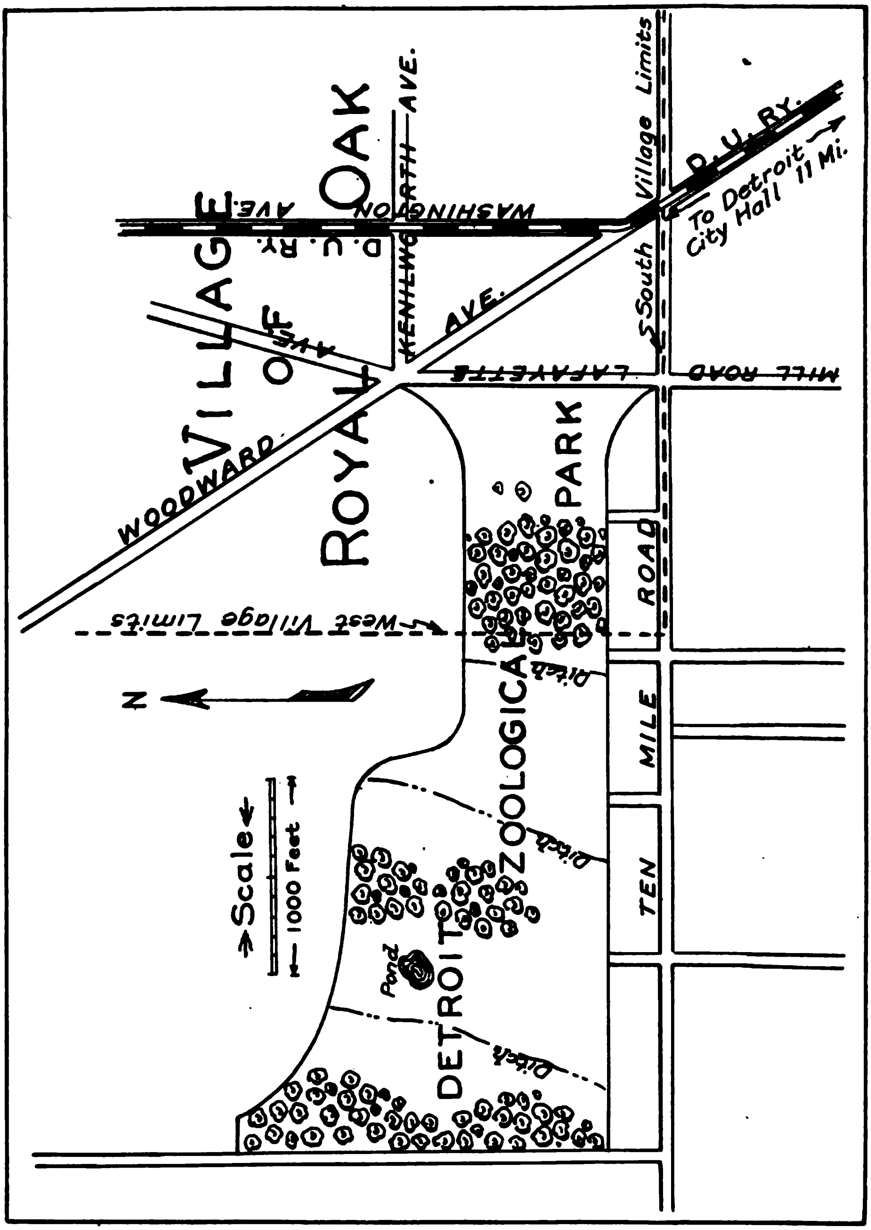


Figure 13. Map of Detroit Zoological Tract.

TYPHACEÆ—Cat-tail Family.

*Typha angustifolia* L.

ALISMACEÆ—Water-Plantain Family.

*Sagittaria arifolia* Nutt.

GRAMINEÆ—Grass Family.

*Panicum linearifolium* Scribn.
*Panicum latifolium* L.
*Phleum pratense* L. Timothy.
*Agrostis alba* L.
*Poa pratensis* L. Kentucky Blue Grass.

CYPERACEÆ—Sedge Family.

*Cyperus strigosus* L.
*Cyperus filiculmis* Vahl. Var. *macilentus* Fernald.
*Eleocharis obtusa* (Willd.) Schultes.
*Eleocharis palustris* (L.) R. & S.
*Scirpus atrovirens* Muhl.
*Carex cristata* Schwein.
*Carex straminea* Willd.
*Carex vulpinoidea* Michx.
*Carex stipata* Muhl.
*Carex Sartwellii* Dewey.
*Carex stricta* Lam.
*Carex gracillima* Schwein.
*Carex pennsylvanica* Lam.

JUNCACEÆ—Rush Family.

*Juncus acuminatus* Michx.
*Luzula campestris* (L.) DC. Var. *multiflora* (Ehrh.) Celak.

LILIACEÆ—Lily Family.

*Oakesia sessilifolia* (L.) Wats.
*Smilacina racemosa* (L.) Desf. False Spikenard.
*Maianthemum canadense* Desf.
*Trillium grandiflorum* (Michx.) Salisb.

SALICACEÆ—Willow Family.

*Salix amygdaloides* Anders. Peach-leaved Willow.
*Populus grandidentata* Michx. Large-toothed Aspen.

FAGACEÆ—Beech Family.

*Quercus alba* L. White Oak.

### URTICACEÆ—Nettle Family.

*Urtica gracilis* Ait.

### SANTALACEÆ—Sandalwood Family.

*Comandra umbellata* (L.) Nutt.

### POLYGONACEÆ—Buckwheat Family.

*Rumex crispus* L. Yellow Dock.
*Rumex Acetosella* L. Field sorrel.
*Polygonum lapathifolium* L.
*Polygonum Hydropiper* L. Common Smartweed.
*Polygonum hydropiperoides* Michx.

### AMARANTHACEÆ—Amaranth Family.

*Amaranthus retroflexus* L. Pigweed.
*Amaranthus hybridus* L.

### CARYOPHYLLACEÆ—Pink Family.

*Stellaria longifolia* Muhl.
*Lychnis alba* Mill. White Campion.
*Silene antirrhina* L. Sleepy Catchfly.
*Saponaria officinalis* L. Soapwort.

### RANUNCULACEÆ—Crowfoot Family.

*Ranunculus sceleratus* L. Cursed Crowfoot.
*Ranunculus abortivus* L. Small-flowered Crowfoot.
*Ranunculus recurvatus* Poir. Hooked Crowfoot.
*Ranunculus pennsylvanicus* L. f. Bristly Crowfoot.
*Thalictrum dasycarpum* Fisch. and Lall.
*Anemone cylindrica* Gray.
*Anemone quinquefolia* L. Wood Anemone.
*Caltha palustris* L. Marsh Marigold.
*Aquilegia canadensis* L. Wild Columbine.

### MENISPERMACEÆ—Moonseed Family.

*Menispermum canadense* L.

### LAURACEÆ—Laurel Family.

*Sassafras variifolium* (Salisb.) Ktze.

### Cruciferæ—Mustard Family.

*Thlaspi arvense* L. Penny Cress.
*Lepidium virginicum* L. Wild Peppergrass.
*Brassica arvensis* (L.) Ktze. Charlock.
*Brassica nigra* (L.) Koch. Black Mustard.
*Sisymbrium altissimum* L. Tumble Mustard.
*Erysimum cheiranthoides* L. Worm-Seed Mustard.
*Radicula palustris* (L.) Moench. Marsh Cress.
*Arabis glabra* (L.) Bernh. Tower Mustard.

### Saxifragaceæ—Saxifrage Family.

*Ribes floridum* L'Her. Wild Black Currant.

### Rosaceæ—Rose Family.

*Spiraea salicifolia* L. Meadow-sweet.
*Pyrus coronaria* L. American Crab.
*Pyrus melanocarpa* (Michx.) Willd.
*Amelanchier canadensis* (L.) Medic. Var. *Botryapium* (L. f.) T. and G.
*Fragaria virginiana* Duchesne.
*Potentilla monspeliensis* L.
*Potentilla argentea* L. Silvery Cinquefoil.
*Potentilla canadensis* L.
*Geum strictum* Ait.
*Rubus triflorus* Richards. Dwarf Raspberry.
*Rubus allegheniensis* Porter.
*Rubus villosus* Ait. Dewberry.
*Rosa humilis* Marsh.
*Prunus serotina* Ehrh. Wild Black Cherry.
*Prunus pennsylvanica* L. f. Wild Red Cherry.
*Prunus americana* Marsh. Wild Plum.

### Leguminosæ—Pulse Family.

*Baptisia tinctoria* (L.) R. Br. Wild Indigo.
*Lupinus perennis* L. Wild Lupine.
*Trifolium pratense* L. Red Clover.
*Trifolium repens* L. White Clover.
*Trifolium agrarium* L. Yellow Clover.
*Melilotus alba* Desr. White Sweet Clover.
*Medicago sativa* L. Alfalfa.
*Robinia Pseudo-Acacia* L. Common Locust.
*Desmodium nudiflorum* (L.) DC.
*Lathyrus palustris* L.

GERANIACEÆ—Geranium Family.

*Geranium maculatum* L. Wild Cranesbill.

POLYGALACEÆ—Milkwort Family.

*Polygala sanguinea* L.

EUPHORBIACEÆ—Spurge Family.

*Euphorbia Esula* L.
*Euphorbia Cyparissias* L. Cypress Spurge.

ANACARDIACEÆ—Cashew Family.

*Rhus copallina* L. Dwarf Sumach.

AQUIFOLIACEÆ—Holly Family.

*Ilex verticillata* (L.) Gray. Winterberry.

ACERACEÆ—Maple Family.

*Acer Negundo* L. Box Elder.

BALSAMINACEÆ—Touch-me-not Family.

*Impatiens biflora* Walt. Spotted Touch-me-not.

VITACEÆ—Vine Family.

*Vitis cordifolia* Michx. Frost Grape.

MALVACEÆ—Mallow Family.

*Malva rotundifolia* L. Common Mallow.

HYPERICACEÆ—St. John's-wort Family.

*Hypericum perforatum* L. Common St. John's-wort.
*Hypericum canadense* L.

CISTACEÆ—Rockrose Family.

*Helianthemum canadense* (L.?) Michx. Frostweed.

VIOLACEÆ—Violet Family.

*Viola latiuscula* Greene.
*Viola papilionacea* Pursh.
*Viola fimbriatula* Sm.
*Viola sagittata* Ait.
*Viola blanda* Willd.
*Viola scabriuscula* Schwein. Smooth Yellow Violet.
*Viola conspersa* Reichenb.

ONAGRACEÆ—Evening Primrose Family.

*Ludvigia palustris* (L.) Ell. Water Purslane.
*Epilobium adenocaulon* Haussk.
*Oenothera biennis* L. Common Evening Primrose.

ARALIACEÆ—Ginseng Family.

*Aralia nudicaulis* L. Wild Sarsaparilla.

UMBELLIFERÆ—Parsley Family.

*Sanicula marilandica* L.
*Osmorhiza Claytoni* (Michx.) Clarke.
*Cicuta maculata* L. Spotted Cowbane.
*Sium cicutaefolium* Schrank. Water Parsnip.

CORNACEÆ—Dogwood Family.

*Cornus Amomum* Mill. Silky Cornel.
*Cornus Baileyi* Coult. and Evans.
*Cornus stolonifera* Michx. Red-osier Dogwood.
*Cornus paniculata* L'Her.
*Nyssa sylvatica* Marsh. Black Gum.

ERICACEÆ—Heath Family.

*Pyrola elliptica* Nutt. Shin Leaf.
*Gaultheria procumbens* L. Checkerberry.
*Gaylussacia baccata* (Wang.) C. Koch. Black Huckleberry.
*Vaccinium pennsylvanicum* Lam. Low Sweet Blueberry.

PRIMULACEÆ—Primrose Family.

*Lysimachia terrestris* (L.) B S P.
*Steironema ciliatum* (L.) Raf.
*Trientalis americana* (Pers.) Pursh. Star Flower.

APOCYNACEÆ—Dogbane Family.

*Apocynum androsaemifolium* L. Spreading Dogbane.

ASCLEPIADACEÆ—Milkweed Family.

*Asclepias tuberosa* L. Butterfly-weed.
*Asclepias purpurascens* L. Purple Milkweed.
*Asclepias syriaca* L. Silkweed.

CONVOLVULACEÆ—Convolvulus Family.

*Convolvulus spithamaeus* L.
*Convolvulus sepium* L. Hedge Bindweed.

### VERBENACEÆ—Vervain Family.

*Verbena hastata* L. Blue Vervain.

### LABIATÆ—Mint Family.

*Scutellaria lateriflora* L. Mad-dog Scullcap.
*Scutellaria galericulata* L.
*Nepeta Cataria* L. Catnip.
*Leonurus Cardiaca* L. Common Motherwort.
*Monarda mollis* L.
*Pycnanthemum virginianum* (L.) Durand and Jackson.
*Lycopus lucidus* Turcz., Var. *americanus* Gray.
*Mentha arvensis* L. var. *canadensis* (L.) Briquet.

### SOLANACEÆ—Nightshade Family.

*Solanum Dulcamara* L. Bittersweet.
*Physalis pubescens* L.

### SCROPHULARIACEÆ—Figwort Family.

*Verbascum Thapsus* L. Common Mullein.
*Pentstemon hirsutus* (L.) Willd.
*Mimulus ringens* L.
*Ilysanthes anagallidea* (Michx.) Robinson.
*Veronica virginica* L. Culver's-root.
*Veronica Anagallis-aquatica* L. Water Speedwell.
*Pedicularis canadensis* L. Wood Betony.

### PLANTAGINACEÆ—Plantain Family.

*Plantago lanceolata* L. Rib Grass.
*Plantago aristata* Michx.

### RUBIACEÆ—Madder Family.

*Galium Aparine* L. Goose Grass

### CAPRIFOLIACEÆ—Honeysuckle Family.

*Viburnum Opulus* L., var. *americanum* (Mill.) Ait.
*Viburnum Lentago* L. Sweet Viburnum.
*Sambucus canadensis* L. Common Elder.

### CAMPANULACEÆ—Bluebell Family.

*Campanula aparinoides* Pursh. Marsh Bellflower.

### LOBELIACEÆ—Lobelia Family.

*Lobelia spicata* Lam.

COMPOSITÆ—Composite Family.

*Eupatorium purpureum* L. Joe-Pye Weed.
*Grindelia squarrosa* (Pursh.) Dunal.
*Solidago canadensis* L.
*Solidago serotina* Ait.
*Aster macrophyllus* L.
*Erigeron philadelphicus* L.
*Erigeron annuus* (L.) Pers. Daisy Fleabane.
*Erigeron ramosus* (Walt.) B S P.
*Erigeron canadensis* L.
*Antennaria fallax* Greene.
*Antennaria neodioica* Greene.
*Ambrosia artemisiifolia* L.
*Rudbeckia hirta* L. Black-eyed Susan.
*Helianthus giganteus* L.
*Helianthus divaricatus* L.
*Coreopsis tripteris* L. Tall Coreopsis.
*Bidens trichosperma* (Michx.) Britton. Tickseed Sunflower.
*Achillea Millefolium* L. Common Yarrow.
*Anthemis arvensis* L. var. *agrestis* (Wallr.) DC.
*Senecio aureus* L. Golden Ragwort.
*Cirsium muticum* Michx. Swamp Thistle.
*Cirsium arvense* (L.) Scop. Canada Thistle.
*Krigia amplexicaulis* Nutt. Cynthia.
*Taraxacum erythrospermum* Andrz. Red-seeded Dandelion.

# THE LEAF-SPOT DISEASE OF RED CLOVER CAUSED BY MACROSPORIUM SARCINAEFORME CAV.

BY L. J. KRAKOVER.*

19th Mich. Acad. Sci. Rept., 1917.

*A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at the Michigan Agricultural College. Paper read at 21st annual meeting.

## TABLE OF CONTENTS.

## INTRODUCTION.

Diseases of red clover are common and are of great economic importance. Nevertheless, little attention has been given them. These diseases are doubtless as widespread as the culture of the plant, and although the annual loss caused has not been accurately determined, it is certainly large. In recent years the culture of red clover has rapidly decreased in extent. The factors producing this change in agricultural practice are doubtless many, but fungous diseases are believed to play an important rôle. The general abandonment of a crop of such agricultural importance must give rise to apprehension. Investigations which throw light upon the diseases of this plant are especially in demand at this time, and close research is warranted by the seriousness of the situation. The very important hindrance to the culture of red clover known as "clover sickness" or failure to secure a "catch" may eventually be found to be a soil problem which is to be solved by proper soil management. The control of fungous diseases of the crop, however, opens up a big field of endeavor. There can be no doubt that important gains in yields will come with prevention of the ravages of disease.

This paper deals with a leaf-spot disease of red clover, caused by *Macrosporium sarcinaeforme* Cav. This disease was very serious in the vicinity of East Lansing, Michigan, during the entire growing season of 1915. It is probably the most important leaf disease of the red clover.

This work was done at the botanical laboratory of the Michigan Agricultural College, under the direction of Dr. E. A. Bessey and Dr. G. H. Coons, whose help and encouragement throughout the work and in the preparation of the manuscript, I wish to acknowledge.

## HISTORICAL.

The first mention in the literature of the red clover disease caused by *Macrosporium sarcinaeforme* was made by Cavara, F., (1890) who discovered it in the vicinity of Pavia, Italy. He gave a brief description of the casual organism and named it *Macrosporium sarcinaeforme* Cav. He characterized the disease as "a leaf spot." Tubeuf and Smith (1897) in their text book were the next to record the disease, but added nothing new. Malkoff, V. K., (1902) found the disease at Göttingen, Germany. He inoculated the organism upon red clover leaves kept damp under a bell jar, and observed characteristic spots within five to seven days.

His description of the fungus differs in certain details from that of Cavara and from that given in this article. A discussion of these differences will be taken up later (p. 282).

Volkart, A., (1903-1904), first recorded the presence of the disease in Switzerland, remarking that heretofore the disease was known only in Germany and in Italy.

Orton, W. A., (1904), in discussing the American plant diseases for 1903, stated, "Comment was also caused by the presence of clover leaf-spot *Macrosporium sarcinaeforme* Cav. and *Phyllachora trifolii* (Pers.) (Fckl.) in Connecticut and New York.

Bain, S. M., and Essary, S. H., (1905), noted the disease in Tennessee thus: "A rather destructive disease caused by *Macrosporium sarcinaeforme* Cav. is very frequent and widely distributed. It often appears on stray alsike plants associated with red clover. The Macrosporium disease appears to be capable of destroying the plants unassisted though the statement is made only on field observation."

Under the name of "Macrosporiose" the disease is referred to as widely disseminated in America by Stevens and Hall (1910).

Milburn, F., (and Bessey, E. A.,) (1915), stated that "the fungus caused considerable damage on the leaves and stems of clover and lucerne, and that it had been found inside the seed, causing non-germination. Such diseased seed is shrunk and wrinkled, and much darker than healthy seed. The mode of infection is not known, but in all probability it spreads from the stems and leaves to the seed." Dr. E. A. Bessey informed the author that he confirmed the presence of the fungus within seed sent to him from England by Milburn.

## ECONOMIC IMPORTANCE.

Since the disease has been so little noticed, little or nothing has been recorded concerning the loss which it causes. However, during seasons which are favorable to its spread the damage caused may be very great. In East Lansing, during the 1915 season, fields were observed where the damage ranged from a loss of 15 to 40 per cent of the crop. The loss may be especially great when, as is often the case, the young crop is attacked. The nature of the damage caused in the United States is in certain cases given in the report of distribution, given below.

## DISTRIBUTION.

The disease seems to be widely distributed on red clover, in Europe and the United States. In Europe it has been reported from Italy, (Cavara, 1890), Germany (Malkoff, 1902), Switzerland, (Volkart, 1903, 1904), and England, (Milburn, 1915). In the herbarium of the U. S. Dept. of Agriculture there are specimens collected in Moravia, Austria,

and Saxony, Germany. The same herbarium also contains specimens collected in 1889 in Manhattan, Kansas,—probably the first specimens collected in this country. The Michigan Agricultural College herbarium contains specimens collected by C. F. Wheeler in the local Botanical Garden in 1898. Other specimens contained in the U. S. Dept of Agriculture herbarium were collected at Houlton, Me., (1906), Arlington Farm, Va., (1907), Germantown, Md., (1908), and Philadelphia, Pa., (1909), besides one specimen on *Trifolium sp.* collected at Potomac Flats, Va., (1890).

The records* of the Plant Disease Survey of the Bureau of Plant Industry report that the disease was common and injurious in certain fields in Connecticut in 1903; widely distributed in Tennessee in 1905; caused great loss of young clover in West Virginia in 1906, but was unimportant in 1910, 1911 and 1912. It was reported from Minnesota for the first time in 1910.**

The collections of the herbarium of the U. S. Department of Agriculture also record the disease on four specimens of alfalfa. Slides from some of this material were kindly sent for examination. It at once became evident that the fungus on alfalfa is not the same as that on red clover. Slide mounts of spores on material collected in Philadelphia, Pa., and Arlington Farm, Va., (Turkestan alfalfa) contained spores which in shape and color are the same as the spores of *Macrosporium sarcinaeforme* Cav. on clover, but they are smaller in size and decidedly warty. On the strength of these morphological differences, the author believes that the fungus on alfalfa is a new species of Macrosporium, and is surely not identical with *M. sarcinaeforme* Cav. on red clover. A search of the literature has failed to reveal a species of Macrosporium which conforms with this Macrosporium on alfalfa. A more complete description of this fungus will be given at another time.

### SIGNS OF THE DISEASE.

*On the leaves:*

Usually within 24-36 hours after inoculation, a minute light brown spot just visible with a hand lens, appears on the leaf surface as a result of the penetration of the fungus. After three days, it has attained a size of 2-3 mm. diameter but has no definite shape. After this it enlarges rapidly, and the typical concentric markings begin to form. The center of the well developed spot is darkest and very distinct. Around this appear the alternately lighter and darker concentric rings. The darker rings are sepia to dark brown in color, the lighter ones, ochre to

*Obtained through the courtesy of Mr. N. L. Lacey.

**The author found the disease quite common on the N. D. Agricultural College farm in the fall of 1916.

light brown. Toward the center the dark rings form ridges and are narrow, while towards the margin they are broad and not raised. The color contrasts between the two outermost rings is very sharp. Conidiophores and spores usually appear first on the under side of the leaf, and can be seen with a hand lens as tiny black clusters, densest nearest the center of the spot. Spores on the upper side of the spot may appear simultaneously with those on the lower side, or later. The spots are oval or round, and after seven days attain the size of 4-7 mm. x 3-5 mm. The lesions, if isolated, may increase in size, the maximum noted being 18 x 8 mm. (Plate XII.)

The spots resemble in general other Macrosporium or Alternaria leaf spots. They are easily distinguished from the spots caused by *Pseudopeziza trifolii,* which do not have well-marked concentric rings. The characteristic central apothecium also characterizes the *Pseudopeziza trifolii* spot. In the early stages of infection, however, it is difficult to distinguish between them.

Spots seem to be most frequent toward the edge of the leaf. Those adjacent to each other soon run together and the death of the tissue lying beyond them follows. This is especially true when the attack is near the edge of the leaf (Plate XIII, Fig. 8). Sometimes a large area is completely covered with small spots which run together (Plate XIII, Fig. 10a). The spots become dry and brittle with age and eventually cause the death and drying out of the entire leaf. If the weather is dry such leaves may hang on for a few days and then fall to the ground. During wet weather they cling to the plant and in the case of the lower leaves, the petioles droop and the leaves soon rot in the wet soil.

*On the petioles:*

An attack on the petiole is very uncommon, and it seems to be restricted to those which are young and succulent. Upon them the fungus appears in the form of dark brown to black linear streaks, one to three mm. long. Little black clusters of spores may be seen on the surface of these streaks (Plate XIII, Fig. 12). A type of petiole infection which results from spores from the leaves is described on page 286 (Plate XIII, Fig. 9a).

### ETIOLOGY.

*Formal Proof of Pathogenicity of Macrosporium sarcinaeforme:*

*Macrosporium sarcinaeforme* was isolated from the typical leaf spots several times during the course of this study. In fulfilling Koch's rules of proof, the fungus from one of these isolations was inoculated into red clover leaves, and reisolated from one of the resulting diseased spots. The fungus from the second isolation was sprayed upon another plant,

the disease produced, and the fungus again isolated. There is no question of the causal relationship of the fungus to this disease.

### DESCRIPTION OF THE CAUSAL ORGANISM.

The causal organism is a fungus characterized by dark septate mycelium, which ramifies through the host tissue, and gives rise to short, erect conidiophores which bear single, dark brown, muriform spores. These are the characters of the genus Macrosporium of the Fungi Imperfecti.

The specific characteristics of the spores, conidiophores, and mycelium are as follows:

*Spores:*

The spores are muriform, sarcina-like (packet) in shape, constricted in the middle, and usually separated at that point into two distinct parts by a cross wall. These parts are subdivided by transverse and longitudinal partition walls which are ordinarily not as thick as the outer or the medium division wall. A spore viewed from the point of attachment shows a small circular scar where it was attached to the conidiophore. The contents of the spore consist of a dense, hyalin protoplasm with many globules (mostly oil) which ooze out when the spore is crushed. The color ranges from hyalin in the very young to dark brown or fuliginous in the older spores. Occasionally a yellow-colored spore may be seen fully developed in form and size, but such a spore darkens with age. The surface of the spore is smooth and no roughenings or prominences of any sort have ever been seen. The size ranges from 22.4-37.7 x 19.1-27.4 microns, with an average of 28.9 x 22.4 microns.

*Conidiophores:*

The conidiophores are usually borne at an approximate right angle to the mycelium which gives rise to them. They are dark brown to fuliginous in color, and on the host are 23.2-74.7 microns long by 5.0-5.1 microns wide. The tip cell which is darkest in color is swollen and flattened, resembling in shape the knob of a pestle. The two or three cells nearest the tip of the conidiophore have a more homogeneous and finely granular contents than the basal cells. These basal cells frequently bear knobs (Plate XIII, Fig. 2). Sometimes on the host, but rarely in culture, the tip cell of the conidiophore instead of at once giving rise to a spore, sends out another cell which is similar to it in shape and structure. The spore is then produced upon this secondary tip cell (Plate XIII, Fig. 3).

*Mycelium:*

The young mycelium in culture is more or less vacuolate and finely granular in structure, sparingly septate, branched, and 2.5-4.0 microns

in diameter. As it grows older it darkens to a brown or fuliginous color and attains a diameter of 4.0-5.1 microns. Within the tissues of the well developed spot the mycelium is sparingly branched and does not exhibit the modifications which appear in culture. The types of mycelium found when the fungus is grown on culture media of the various sorts will be described later.

In comparing the organism studied with those described by Cavara and Malkoff, several differences may be noted, especially with regard to the size of spores and the lengths of conidiophores. The following is a comparative table:

Table 1.

Measurements of Spores and Conidiophores. Comparison of Published Records with Michigan Material.

| | Spores. | Conidiophores. |
|---|---|---|
| Cavara | 24-28x12-18 microns | 14-18 microns long |
| Malkoff | 25.2-33.6x16.8-22.4 microns | 95.2-142.8x4.2 microns |
| Author | 22.4-37.7x19.1-27.4 microns<br>Avg. 28.9x22.4 microns[a] | 30-154x4.9-5.1 microns<br>Avg. 77x5.0 microns[b]<br>On host: 23.2-74.7x5-5.1 microns |

a These figures are the averages of 217 measurements made upon spores grown on seven different media; age of cultures 1 to 8 weeks.
b Average of 58 measurements made from four of the above cultures.

Since Cavara makes no mention of having cultured the fungus his measurements were evidently made from that growing on the host. It will be noted that his spore and conidiophore sizes are smaller than those of both Malkoff and the author, especially in regard to the width of the spores. A specimen issued by Briosi and Cavara[1] was available for examination. The few spores which were found when measured, agreed fairly well with the size he gives. The measurement of only a few very old spores cannot be considered as a criterion, but there is no reason to believe that Cavara was mistaken in his measurements. It is possible, however, that he measured the very young spores. The figure which accompanies the herbarium specimens looks very much like that of a young spore.

The measurements of Malkoff and those of the author agree closely enough, so that at least in this respect they may be considered the same. The author has measured the spores from material collected in various parts of the United States and finds that they agree in size with those found in East Lansing, Mich.

[1]Briosi and Cavara—I Funghi parassiti delle piante coltivate od utili. 116.—*Macrosporium sarcinaeforme* Cav., in Difesa dia parassiti N. 4. Milano 1890.

Malkoff believes that the fungus he observed was perhaps not exactly the same as that described by Cavara, for, he remarks, "If my diagnosis is compared with the original diagnosis (Cavara), one may see that they entirely agree except for the *size and form of conidia, which are not entirely sarcina-like.*"

Just what he meant by "not entirely sarcina-like" or whether his conception of the term sarcina was different cannot be determined. That the fungus studied by the present author, may, by analogy with the coccus bacteria grouped in packets, (*Sarcina lutea,* for example), be considered as sarcina-form, is entirely within the common acceptation of this term. This is evidently what Cavara had in mind when he named the fungus.

While the average length of the conidiophores when the fungus is grown on culture media is greater than that of those growing on the host, the length of the conidiophores is given by Cavara is much less than that given by the author. According to the former's measurements, they are only a little over one-half the length of the spore (12-18:24-28), while his figure represents the ratio as about 2:1, an apparent contradiction.

One important point, wherein Malkoff differs with both Cavara and the author, would indicate that he was perhaps dealing with another species. He states that the spores are somewhat warty. Cavara does not mention this (a point he could have hardly overlooked) and the author has not found this to be the case with spores from the material of Cavara and other sources. In this connection the warty spores on alfalfa already referred to, is of interest.

There is also considerable difference in the appearance of the leaf spots on Cavara's material, (herbarium specimen) and on his figure which accompanies it. The spots as compared with American specimens, are smaller, far more numerous, irregular in shape, and do not bear the concentric markings so typical of the spot on the latter specimens. The small size and greater number of spots may be due to the smoothness of some European varieties of red clover. A smooth leaf surface has a better chance of retaining many small droplets of moisture than a hairy surface, whereon the droplets have a tendency to collect in one or several large drops on the hairs. A photograph of a diseased leaf accompanies the description given by Malkoff, but it is too blurred to be of any use for comparison.

The specimens collected in Manhattan, Kan., in 1889 and identified later by G. H. Hicks, bear a question mark after the name, (*Macrosporium sarcinaeforme* Cav.?) indicating that this critical mycologist had some doubt as to whether it was the same fungus.

Whether these differences in spore size and parasitic habit are sufficient to differentiate species or sub-species, must be left for further work. With abundant material from Europe and America, and by cultural and infection studies this problem could readily be solved. For the present, having recorded the observed differences, the writer retains the old name, *Macrosporium sarcinaeforme* Cav., for the etiological factor in this disease.

### INFECTION PHENOMENA.

*How the fungus enters the host:*

The following method was used in determining how the fungus enters the host: A leaf attached to the living plant was inserted through the opening in the stage of the microscope from which the sub-stage had been removed. One of the leaflets was clamped in place by means of clips and a small drop of spore suspension placed upon its surface. The germination of the spores could thus be observed under the low power of the microscope. A fresh drop of water was added from time to time to prevent drying.

Usually germination begins within two to three hours after inoculation. Within ten to fourteen hours the germ tubes have attained a length of four to six times that of the spore, after which, penetration begins. This is best observed by focusing the high power directly into the drop, using for illumination light from a small arc directed at the sub-stage mirror.

The germ tube appears to enter between the epidermal cells. A few cases of stomatal entrance have been observed, but this is not characteristic.

Where it was desirable to examine more closely the means of penetration, the leaf was treated in the following manner: The spores were permitted to dry down on the leaf and a piece of the tissue in which penetration had occurred was fixed in 95% alcohol for one hour. This treatment removed the chlorophyll and made the tissue almost transparent. The material was then stained in eosin, 5-10 minutes, cleared in phenol-turpentine, and mounted in balsam. The germ tubes were stained a deep pink and the leaf tissue a lighter shade of the same color. Tissues stained in this manner showed plainly the mode of entrance of the germ tube, and the mycelium which has already begun to grow through the leaf tissue could be easily observed.

*Infection Experiments:*

In performing these experiments three general methods of inoculation were used. These will be referred to by number in the subsequent discussions, where convenient.

Method 1—The plants are first drenched with water (sprinkling pot) and then sprayed with a suspension of spores in sterile water. The plants are then kept in a humid atmosphere under a bell jar. It was found that the droplets containing the spores adhere much better if the leaves are first drenched with water. By this method, characteristic spots develop within five to seven days.

Method 2—Small masses of fungus growth (spores and mycelium) are placed upon the upper surface of the leaflets, the inoculum covered with a tuft of cotton, and the plants kept under a bell jar as above.

Method 3—A drop of spore suspension is carefully placed upon the leaflets by means of a capillary pipette and then covered with a tuft of cotton. This retains the moisture and prevents the droplet from rolling off the leaf. The plants are kept under a bell jar.

Inoculations made by either of the last two methods do not give typical spots. The leaf tissue surrounding the inoculum was progressively killed within twelve to fifteen days.

During this study red clover plants were inoculated many times under a variety of conditions, using all the methods above described. Successful infection was almost invariably secured. (The failure to secure inoculations after long cultivation of the fungus will be discussed later.)

*Infection experiments with young and old leaves:*

The following experiment was undertaken to determine the relative susceptibility of red clover plants in the various stages of their development:

Table 2.

Infection of Plants in Various Stages of Development: Test with Potted Plants under Bell Jars.

| Group | Plant. | Amount of spore suspension. | Results after 8 days. |
|---|---|---|---|
| 1 | Number (more than 50) of healthy rapidly growing seedlings about 5 cm. high, grown in greenhouse in a large flower pot. Age 3 weeks. | 2 ejections from atomizer | All but a few leaflets infected. |
| 2 | Number (more than 10) of healthy plants about 33 cm. high, transplanted from field to greenhouse. | 20 cc. | About one-half of leaves infected, especially lower and central leaves. |
| 3 | Two large leafy plants about 55 cm. high transplanted from field to greenhouse. Soil surrounding roots not disturbed in transplanting. | 30 cc. | About one-third of leaves infected with heaviest infection in lower and central leaves. |

All diseased or otherwise weakened leaves were removed from the plant. All were drenched with water and sprayed with a suspension of spores. An effort was made to make the amount of spray as nearly as possible proportional to the quantity of foliage in each group.

From these infection experiments and the general observations throughout the work, besides observation in the field, it seems likely that the very young leaves are more susceptible to the attack of the fungus than are the older leaves. This is perhaps due to the more tender and succulent condition of the young leaves. As a corrolary of the leaf condition, we find young plants more susceptible than old. For example, in West Virginia, in 1905, the disease was reported as causing a great loss of young clover.

*Stem and petiole infection:*

Although numerous infection experiments by spraying a suspension of spores upon the plant were made, in no case was the infection of the stems or petioles observed as the result of such a method of infection. This may be due to the fact that a drop.of spore-containing water adheres with difficulty to these parts of the plant and may roll off before the fungus has a chance to penetrate. Infection of the petioles, however, was readily obtained by inoculating with a small mass of fungus growth and then tieing cotton around the part inoculated. Within five to seven days dark brown to black, linear streaks developed. Similar attempted inoculations made upon the stems have not been successful. In another experiment, longitudinal slits about 1 cm. in length, were made upon four old, woody stems, and the fungus inserted in the wound. Even after two weeks there was no sign of infection. Some of the inoculum was removed and examined: the spores had merely germinated but seemed to have been incapable of proliferating the tissue of the stem. This may be due to the comparative dryness of these older stems.

Only in a few rare cases have infected petioles been seen in the field. Young leaflets when inoculated by Method 2 may be eventually destroyed and the fungus spread from them to the petiole. Petioles so infected have a black, pinched appearance near the base of the leaflets (Plate XIII, Fig. 9a).

*Floral and Seed Infection:*

Floral infections were undertaken with the idea of infecting the seed. Reference to the statement of Milburn (1915) concerning the presence of the fungus in the seed, has already been made. At various times during the summer flower heads of red clover in early, full, and late bloom respectively were inoculated by Method 1, but in no case was the infection of any floral part of the seed obtained. Flowers from plants

in the field whose leaves were badly infected with the disease were often examined but the fungus was never found growing upon them.

It was found that the fungus grew readily upon disinfected seed (soaked in $HgCl_2$, 1:1000 for 20 minutes, and rinsed in sterile distilled water) which had just enough water present to allow the seed to germinate. The growth of the fungus was rapid and abundant. Within two weeks the entire mass of seed was well overrun, and an abundance of spores produced. The seed coats were almost completely covered by the fungus and eventually destroyed. The cotyledons of germinating seeds could be seen emerging from a black fungus shell of what had been the seed coat. The cotyledons were not attacked, though some of them were slightly discolored, but the tip of the radical, which in some cases attained the length of 10 mm. was attacked by the fungus and killed, thereby preventing further growth. It is possible that as the seed dried out somewhat, the growing tip died and was attacked saprophytically. However, some of the radicals were attacked just as they were emerging from the seed. The large bulk of the seed was so completely enveloped by the fungus that they could not even germinate. Some of these seeds were planted but failed to grow.

From these experiments and from the observations made by Milburn already referred to, there is a possibility of seed carrying the fungus as threads within the seed coat. The failure of attempts to infect the growing flower parts, and the absence of characteristic lesions on the young cotyledons seem to indicate that the fungus threads within the seed coat are not especially important in causing infection of the young plant. The discussion of this latter phase is taken up under the topic, Dissemination.

*Humidity and Infection:*

In the series of infection experiments already reported, care was taken to insure a humid atmosphere after inoculation. The germination studies reported on page 304 proved that the lowest relative humidity at which air dry spores will germinate lies between 92.8 and 93.4%.

Experiments with *Septoria lycopersici* performed in this laboratory (Levin, 1916) has shown that this pathogene could infect without the film of water commonly held essential for germination. It seemed, therefore, proper that the relation of infection by the clover fungus be similarly determined. Red clover plants were inoculated by placing small masses of air dry fungus growth (culture 10 days old) upon the surface of many of the leaflets. The plants were then well watered and the soil and outside of the pots completely covered with paraffin to prevent the evaporation of water from any source but the plant. These plants were placed under a sealed bell jar, through which air, previously dried by passing through $H_2SO_4$ and $CaCl_2$, was drawn by means of a suction

pump. The air was passed through continuously for seven days at the rate of about forty bubbles per minute (in $H_2SO_4$). This constantly moving stream of air besides a dish of $CaCl_2$ under the bell jar served to carry off the transpiration moisture. A polymeter was suspended in the bell jar for the purpose of determining the amount of humidity. Humidity and temperature (in the room) were recorded at about eight hour intervals. The former ranged from 10 to 28% and the latter from 17 to 21°C. during the entire seven days. There were no signs of infection at the end of this period, though one of the plants was badly wilted. An inoculated check plant kept under a humid bell jar developed the disease within the usual time.

From these experiments it is evident that the moisture requirements for germination and subsequent infection are high. While this has not, so far as the author is aware, been determined for fungi similar to *M. sarcinaeforme,* fungi of analogous structure would probably have similar high moisture requirements.

It would seem that a parasite, one having entered the host would be independent of the humidity of the atmosphere, because it has already reached a more or less saturated environment. To verify this inference, plants were inoculated and kept under a humid bell jar for 28 hours. A few of the leaflets were then killed in 95% alcohol, cleared in phenol-turpentine, stained, mounted in balsam, and examined under the microscope. The fact of the penetration of the host being established, the plants were then placed under a bell jar containing $CaCl_2$ and a Lambrecht polymeter. In spite of the dryness of the atmosphere which contained 54-57% relative humidity, disease spots developed within six days after being removed to the dry atmosphere. This and the previous experiment would indicate that the humidity of the atmosphere is an inhibiting factor only until the fungus has entered the host. Once having entered, the external humidity is immaterial.

*Relation of light to infection:*

Under field conditions, the lower leaves of the plant are usually infected first, and suffer the most destruction. Aside from their favorable location near the ground, (i. e., favorable with regard to the possibility of infection) this is due for the most part, to the fact that the lower leaves retain more moisture. There is in addition, the factor of light, which might play a more or less important role. To determine this relation, the following experiment was performed:

Four healthy, well developed, potted plants were thoroughly sprayed with a heavy suspension of spores. Each plant was placed under a separate bell jar, and the lower half of two of the jars was covered with black paper, so as to prevent any light from a lateral direction reaching

the lower leaves. The air in the bell jars was kept saturated during the entire experiment. The plants were placed side by side in the greenhouse. Thus all conditions were equal except that the lower leaves of the half darkened plants received only what light filtered through the upper leaves, whereas the other two plants received light from the sides as well. After eleven days a comparison between the two sets of plants showed that the lower leaves of the half darkened plants, besides being partially etiolated, bore more and larger spots than the lower leaves of the fully lighted plants. Twenty leaflets of the former picked at random, bore fifty-one spots compared with thirty-seven spots on a like number of the latter.

In the case of plants kept in total darkness, the fungus was found to infect and spread very rapidly. The spots besides being large caused the death of considerable tissue beyond them. Although darkness has not been found to affect the growth of the fungus itself, it may be that the clover plant, either because of a weakened condition or an increase in succulence has become more susceptible.

### INOCULATIONS UPON OTHER HOSTS.

*Alsike Clover:*

Bain and Essary, (1905), stated that *M. sarcinaeforme* was often found upon stray alsike plants associated with red clover in Tennessee. Repeated attempts were made to infect alsike clover, but without success;

The following experiment which has been repeated several times during this study is typical: A pot of red clover and a pot of alsike clover plants in about the same stage of development were sprayed thoroughly with a suspension of spores, and both pots kept under the same bell jar. Within the usual time the red clover plants were infected, but never the alsike. None of the other methods of inoculating, even using a heavy inoculum, produced infection, and no noticeable effect aside for an occasional slight discoloration of the leaf, has been observed. Wounded leaves also failed to take the disease. Other inoculations were made upon young seedlings and plants in various stages of growth, without success. In the field, completely healthy alsike plants have often been observed growing in the midst of badly diseased red clover.

We may conclude that the strains of alsike clover tested under East Lansing conditions are not susceptible to the strain of *M. sarcinaeforme* found upon the red clover growing in this vicinity. Unless we postulate marked differences in disease resistance in strains of alsike clover, these results seem to indicate that the statement of Bain and Essary (1905) ascribing the leaf spots of alsike and red clover to the same organism is incorrect.

*Other Species:*

Similar inoculation experiments were performed upon crimson clover (*T. incarnatum*), white clover (*T. repens*), sweet clover (*Melilotus alba*), alfalfa (*Medicago sativa*), pea (*Pisum sativum*), bean (*Phaseolus vulgaris*), and vetch (*Vicia villosa*). These were uniformly without success. Among the non-legumes the following plants were tested and found to be not susceptible to the disease: Potato, tomato, cucumber, muskmelon, cabbage, rape, and lettuce. So far as the experimentation has been carried, the red clover is the only plant attacked by this parasite.

THE HOST IN DISEASE.

1. *Morbid Anatomy:*

For a histological study of the diseased tissue, the material was treated in the following manner:

Gilson's fixing fluid, 6-8 hrs.

Washed in 70% alcohol until odor of acetic acid disappeared.

70% alcohol 24 hrs.

From this point, dehydration, embedding, until the sections were ready to stain, were proceeded with in the usual manner.

Staining:—Weak Delafield's haemotoxylon, 4-6 hrs.; wash in water 20-30 min. Eosin, 30-45 sec.; clear in phenol-turpentine; mount in balsam.

The fixing and subsequent treatment failed to remove the brown color from either the dead tissues or the spores and conidiophores. Peroxide of hydrogen likewise failed to bleach this color. By this staining process the mycelium within the tissue was stained deep purple, the healthy tissue, red to light purple, and the diseased tissue either a reddish brown or not at all (retaining its original brown color).

The diseased spots were only about one-third to one-half as thick as the normal tissue. The cells composing the spot were almost completely collapsed. Within the spot proper the cells were almost entirely disorganized and permeated with the older mycelium. This mycelium is brown in color, septate, branching, and of a more or less homogeneous structure without any vacuoles. From both sides of the leaf, at irregular intervals, spore bearing conidiophores project, their length varying from 1-3 times that of the spore.[1]

Near the edge of the spot the young mycelium may be seen spreading intercellularly and to a certain extent intracellularly into the adjacent healthy tissue. The mycelium does not as a rule at once emerge from the leaf, but spreads laterally among the cells and may grow for a considerable distance immediately underneath the epidermis. (Pl. XIV,

[1]This fixing fluid did not, as it is reputed, serve to retain the spores upon the conidiophores.

Figs. 10 and 11.) Usually the hyphae begin to come up through the leaf surface on about the fourth day after inoculation. The hyphae underneath the epidermis turn up and penetrate between the epidermal cells and in some cases a hypha may be seen coming up through a stoma, (Pl. XIV, Fig. 10). The former method is much more common. The hyphae once outside the leaf begin to swell at the tip and produce spores. The process of spore formation will be described later.

2. *Morbid Physiology:*

The work of Levin (1916) with the Septoria leaf-spot diseases of tomato had shown that the newly formed spots on the tomato leaves transpired more than the healthy tissue. With old spots on the contrary no transpiration took place, and this is ascribed to the dead tissue being cut off from the water supply.

An experiment using the method described by Levin was set up to find if in clover there was transpiration from diseased spots. A simple potometer (modification of Ganong's) the construction of which may be

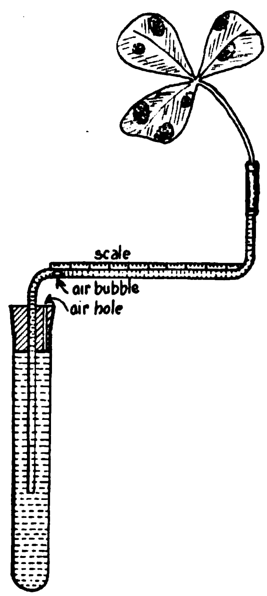


Figure 14. Simple potometer.

easily understood by referring to the diagram (Fig. 14), was used. Into this was fitted a red clover leaf bearing 6-8 large, old disease spots, the place where the petiole enters the tube being sealed by the application of anhydrous lanolin. By careful manipulation, an air bubble was obtained in the horizontal arm of the tube. A paper centimeter scale was then

glued to the outside of the tube so that the zero point was opposite the bubble. Three such potometers were set up. As water evaporated from the leaf, the bubble moved forward, the distance traversed being used on the scale. By this means the relative transpiration was determined. After three hours the distance traversed by the bubble was recorded. The diseased spots were then coated with anhydrous lanolin on their upper and lower surfaces in order to prevent the evaporation of water from these parts. After three hours the reading was again taken.

The following table gives the results:

Table 8.

Transpiration of diseased leaves with spots covered and uncovered.

| Leaf No. | Distance traversed by the bubble. | |
|---|---|---|
| | Spots before covering. | Spots after covering. |
| 1 | 21 mm. | 22 mm. |
| 2 | 17 mm. | 17 mm. |
| 3 | 24 mm. | 23 mm. |
| Avg. | 20.67 mm. | 20.67 mm. |

Hourly readings of the temperature were taken. These ranged from 19° to 20° C.

While this experiment was conducted upon a small scale, yet from the fact that the relative transpiration of the leaves with the spots uncovered checked so closely with that from the leaves with the spots covered, it is fairly certain that the disease spots, at least when old and dried, do not transpire.

No other physiological studies were made upon the diseased host. The damage to the clover plant is for the most part brought about by the direct injury to the leaf surface. The profound unbalancing of root and top leads to rapid growth. The new leaves are again subjected to the same conditions. Thus so long as the weather favors, the plant is being pushed to extra leaf production, and each crop of leaves becomes more severely attacked. The badly diseased leaves cannot perform the photosynthetic functions, so that the growth takes place at the expense of the cell reserves. It is extremely likely that the young diseased spots transpire more than healthy leaf surface, as was found by Levin, but in the case of clover these spots dry out so quickly that excessive water loss does not continue long enough to be very important. We may conclude, therefore, that the chief characteristic of the clover plant in disease is the unbalanced metabolism, and that the injury comes from the constant depletion of the cell reserves.

PHYSIOLOGICAL RELATIONS OF THE CASUAL ORGANISM GERMINATION STUDIES.

The various studies in the germination phenomena of the fungus were made in the usual Van Tieghem cells kept at room temperature (20°-24° C.).

The spores of *M. sarcinaeforme* germinate readily in either tap or distilled water. If taken from a young culture, they begin to germinate within an hour. Usually within six hours every viable cell of the spore has sent out a germ tube. These tubes are at first hyalin and finally granular, but become much vacuolated as they elongate. The limit of growth in water is reached after 36-48 hours. At this stage, the mycelium is somewhat branched, septate, and vacuolate, with a length of 500 to 700 microns. Spore formation in water was not observed. Malkoff (1902) mentions observing the formation of new spores in a hanging drop, but does not state what medium he used.

In clover juice, the germ tubes are at first hyalin but more closely granular than those growing in water. They begin to swell at the base very early, and darken in color. This basal swelling is soon cut off by a cross wall and rounds up into a cell containing one or more large central vacoules. These vacoules enlarge much faster than the cells containing them (Pl. II, Fig. 5 and 6). From this time on the growth of the tubes is more rapid; the mycelium becomes coarsely granular, turning to a brown color which is darkest near the spores and shades off to hyalin at the growing tip. As the mycelium becomes older, the cell walls thicken, and oil globules appear. Within three days the colony attains a diameter of 2-4 mm.

*Spore formation:*

The conidiophore begin to differentiate about the fourth day. A short branch usually at right angles to the main thread, begins to swell at the top. This branch may or may not elongate as the swelling progresses. The swollen cell darkens, and is further differentiated from the vegetative cells in that it is finely granular and contains no oil drops or vacuoles. The first sign of the spore, which usually begins to appear on the fifth day, is a small, hyalin protuberance from the swollen tip cell. This enlarges rapidly, until it emerges as an oval, hyalin cell perched on the tip of the conidiophore. A horizontal cross wall divides the cell in the middle, and soon the first longitudinal divisions appear. As the spore matures the color gradually darkens to a deep brown or fuliginous color, the constriction at the middle becomes more prominent, and the remaining subdivisions are produced. As a rule, the outer cell wall and the median division wall become more thickened than the partition walls of the spore. Sometimes the end of the mycelium which gives rise to the

conidiophores, or even a primary branch becomes modified into a conidiophore and bears a spore. This is the source of some of the abnormally long conidiophores. The process of spore formation is delineated on Plate XIII, Figs. 21-29.

The general method of spore formation is analogous to the process among many of the Alternarias, where a spore sends out a little swelling from the beak end, which later enlarges, becomes muriform, and develops into a spore like that which gives rise to it.

The method of spore formation as observed by the author does not agree with that described by Cavara (1890) or Malkoff (1902), who state that the apical cell of the conidiophore swells, and itself becomes differentiated into the spore. The author has never witnessed this procedure.

In a 5% dextrose solution, growth proceeds to the formation of spores, but the germination process develops abnormal swellings. In a few instances, a cell budding from the spore was seen to enlarge to a size equal to that of the spore which gave rise to it, and become divided by one or two lateral cross walls, giving it the appearance of a young spore (Pl. XIV, Fig. 7). Though this was not seen to develop into a mature spore, it might possibly have done so under proper conditions. This may be evidence of a tendency towards an Alternaria-like habit. Some species of Macrosporium are known to develop the Alternaria habit in culture. The cause of these abnormalties is not due entirely to the nature of the medium, since they did not appear in a series of 5% dextrose solution cultures prepared at another time. The mature mycelium also germinated readily. In water thin hyalin threads, similar to the germ tubes from the spores, are produced. Old conidiophores from which the spores have fallen often germinate from the tip cells, sending out long vacuolate tubes with occasional swellings (Plate XIV, Fig. 9).

The amount of germination of spores from young cultures is practically 100%. In cases where old spores were used, the germination percentage was found to vary from 70 to 90%.

### CULTURAL STUDIES.

The original culture of the fungus was obtained from the dried material, which at the time was 18-20 months old. Dilution plates were poured, using corn meal agar. A single spore was marked, and when germination occurred it was removed together with a small block of agar containing it and transferred to prune-juice agar. From the colony which developed transfers were made, originating the stock cultures.

The comparative cultural study of *M. sarcinaeforme* has not revealed any striking morphological divergences. The fungus grows readily on a large variety of media. Three groups of media were used: agars,

vegetable plugs, and liquids. All cultures in each group were run simultaneously, and growth observed over a period of three weeks.

In general, growth proceeds as follows: The spores germinate within a few hours and after 24-28 hours, small white tufts of aerial mycelium, 1-3 mm. long appear. During the next two or three days the mycelium spreads gradually over the surface of the medium, the rate of spread depending upon the amount of moisture present and the amount of inoculum used. Beginning with the third day, the mycelium usually darkens in color, at first a dull gray woolly appearance which gradually darkens. Spore formation begins on the fifth or sixth day, and as the spores mature and increase in number, the culture assumes a black, felt-like appearance. On agar media, the fungus usually begins to grow down below the surface after the first week. This submerged growth which may extend down 5-10 mm., consists of a dark mycelium and spreads out more or less like the roots of a plant. The maximum amount of growth is reached within 16-20 days.

Of the various agar media used, oat meal agar produces the most abundant growth of mycelium and spores. Plain nutrient and synthetic agars produce the smallest amount of growth. With the addition of glucose or dextrose to the nutrient agar, growth materially increases.

Of the vegetable media used, it is noteworthy that on potato, while a dense mycelial growth was produced, spores were few. The presence of sugar seems to favor spore production. Of these media sugar beet and red table beet rank first in the amount of spores formed, carrot second, parsnip third, and potato last, which also represents, approximately, the relative order of their sugar content. If glucose is added to potato, as in the case of hard potato agar, spores grow in abundance. On the other hand, wheat starch paste (Kahlbaum's) is an excellent medium for spores. A test of the substratum upon which the fungus had been growing for two weeks showed that much dextrose had been formed. The sterile, uninoculated starch paste check gave no such test. Evidently the fungus secretes diastatic enzymes.

On the plain corn meal, growth is abundant, but the hypothetical ascus stage has thus far failed to appear on this medium. (Oldest culture, nine months.) Clover stems, bean pods, and sorghum stems, are very good media for obtaining an abundance of spores.

There are no striking differences in the general appearance of the fungus on the various media studies. All cultures look more or less alike and can be distinguished from each other only in a comparative series. The gross amount of growth and the abundance of spores varies to a certain extent even on the same medium. Again organic media are not always alike even if prepared under the same formula. For example,

in one lot of corn meal agar prepared by a colleague the submerged mycelium extended down to a much greater depth than on the same medium prepared by the author. The dearth of spores on potato, however, seems to be constant on several lots of this medium.

The following tables give a comparison of the growth on the various media, under as uniform conditions as it was possible to obtain. As a quantitative standard of growth, oat meal agar was used for the various agar media, sugar beet for the vegetables, and clover juice for the liquids.

Table 4.

Growth on Liquid Media: Small Flasks.

| | 6 days. | 21 days. |
|---|---|---|
| Clover juice. | Colonies dark gray, 2-8 mm. diameter. A ring of colonies has formed where the liquid touches the glass. Bottom of flask completely covered by white mycelial mat consisting of many small colonies. Spores being formed. | Most of the colonies have grown together, forming a heavy, black spore covered mat. Mycel. on bottom also dense but bears no spores. Best growth obtained from liquid media. |
| Full nutrient solution. | Good surface growth but light in color. Dark ring of colonies around edge of liquid. Spore production slight. | Heavy growth of mycelium throughout the liquid, but spores are not abundant. |

Coons' [1]Synthetic Medium same as Full Nutrient Solution.
Dunham's Peptone Sol. same as Full Nutrient Solution.

[1]Coons, G. H. (1916).

Table 5.

Growth on Nutrient Agar and Vegetables: Test-tube Cultures.

| | 6 days. | 18 days. |
|---|---|---|
| Oat meal agar. | Agar well covered with a dark growth. Spores being formed in abundance. Some dark gray aerial mycelium. | Dense growth covering entire surface of the agar. Mycelium growing out on walls of tube. |
| Prune juice agar. | Growth not as heavy as above; spores being formed; aerial mycelium dark gray. | Growth entirely black; medium in amount as compared with oat meal agar. |
| Corn meal agar. | Good growth about same as on prune agar. Color greenish-black. Mycelium growing down about 3 mm. into agar. | Same as prune agar. |
| Clover juice agar. | Spores not as abundant as on prune agar. Color greenish-black. | Same as prune agar. |
| Hard potato agar. | Color deep black, abundance of spores; submerged mycelium. | Growth abundant. |
| Plain nutrient agar. | Color dark gray; spores just beginning to form. | Growth lightest of all. |
| Nutrient agar plus 5% dextrose. | Heavy black growth; spores abundant; second only to oat agar. | No increase in amount of growth. May be due to drying of agar. |
| Nutrient glucose agar. | Same as dextrose agar. | Growth has spread somewhat otherwise same as dextrose agar. |
| Coons' Synthetic agar. | Ditto. | Ditto. |
| Litmus lactose agar. | Fair amount of growth. Spores present. Litmus beginning to turn blue. | The blue color has diffused through the agar a considerable distance from region of growth. |

Table 6.

Vegetable Media.

| Medium. | 6 days. | 18 days. |
|---|---|---|
| Potato. | About one-half of surface covered by a dark gray growth. Very few spores mostly immature. Mycelium toruloid and coarsely granular. | Growth is black almost completely enveloping the plug. Growth is somewhat brittle, forming a crust about 3 mm. thick. Interior of potato is disorganized and permeated with a hyalin mycelium. Spores very few. |
| Parsnip. | General appearance, texture, amount of growth, and mycelium like that on potato, but spores are much more numerous. | |
| Carrot. | About two-thirds of surface covered by dark gray growth; spores abundant. | Black brittle growth similar to that above. |
| Red table beet. | Black dense growth; spores abundant. | Like carrot. Spore production best of series. |
| Sugar beet. | Like table beet. | Slight greenish tinge; otherwise like red table beet. |
| Clover stem. | Black scattered growth; spores abundant. | Surface growth mostly of short conidiophores covering entire stem; superficial mycelium slight. Interior pervaded by hyalin threads. |
| Sorghum stem. | Black growth; spores abundant; more vegetative mycelium than on clover stem. | Ditto, except for more mycelium. |
| Corn meal. | About two-thirds of surface covered by growth; spores abundant. | Growth has ramified throughout the meal, blackening it. Much better than on corn meal agar. |

On culture media the fungus exhibits many variations in the form and structure of the mycelium which are not found when the fungus is growing within the host. In cultures which are well developed (2-3 weeks), the cells of some of the mycelium are closely packed with highly refractive globules,—mostly oil[1]. Other cells contain only a few larger globules, and an occasional cell may be seen completely filled by a single oil globule. Individual cells may swell up and assume a globular form, with a diameter of 8-11 microns. The submerged mycelium differs from that growing on the surface in that it is toruloid or beaded. Some of these cells form internal cross walls and appear almost like the

[1]Test for oil made with Sudan III; the oil globules were stained light red by this preparation.

beginning of a spore, but further development has not been found. These cells may perhaps be chlamydospores. The branching habit is poorly developed in this mycelium, anything more than a primary branch seldom appearing (Pl. XIII, Figs. 19 and 20).

Upon agar media kept under humid conditions, newly formed spores may germinate directly. In the center of the colony where the growth is very dense, many of the germ tubes sent out at once differentiate into conidiophores and bear spores. (Pl. XIII, Fig. 5.) These newly formed spores are somewhat smaller than the spore from which they arise, ranging in size from 18-24 microns x 11-18 microns. As many as six of these conidiophores varying in length from 12 to 58 microns, have been observed arising from a single spore. This direct spore formation, i. e., from spore to spore without any vegetative mycelium intervening, may be due to the inability of the germ tube to penetrate the dense mass of growth which lies below it, so that the agar,—the source of food,—cannot be reached. If this is the case, such direct spore formation may be the result of starvation. Near the edge of the colony the germ tubes have ready access to the fresh, unoccupied agar, hence vegetative mycelium is produced.

It was noted that in the foregoing spores giving rise directly to the new spores were not attached to the conidiophore upon which they were originally borne. It was thought that the humidity of the surrounding atmosphere might have something to do with the falling of these spores. To determine this, the following experiment was performed:

Some petri dish cultures containing numerous, small, closely crowded colonies, and in which the agar was completely dried out, were used. These were kept in an inverted position for a day or so, that any spores that might fall naturally might be removed. One of these dishes was then suspended in an inverted position over a freshly poured dish of agar, so that any falling spores would be caught. This arrangement was then placed in a deep culture dish in the bottom of which was a little water. A similar arrangement was placed in a deep culture dish without any water, that is, in a relatively dry atmosphere. When examined after ten days the agar underneath the dish in the moist chamber, bore colonies corresponding almost exactly with the location of the colonies in the inverted dish suspended above it, indicating that the spores had been dropped off. The lower dish of agar in the dry chamber contained no growth. The results of this experiment indicate that the humid atmosphere is one of the factors involved in the release of the spores from their conidiophores. This release of the spores may be of the type of ejection similar to that noted in the rusts (Coons 1912) and other fungi.

## METABOLISM.

*Changes in Nitrogenous Media:*

When cultured upon a medium containing either organic or inorganic nitrogen, one of the end products of metabolism is ammonia. The reaction of the medium which is at first acid is slowly changed to alkaline. Thus, in a series of clover-juice cultures (100 cc. in a liter flask) the reaction changed, viz.,

Table 7.

Changes in Reaction of Medium.

| Time. | Reaction. | Reaction of sterile medium. |
|---|---|---|
| 6 days | 3½°[1] Acid | 7° Acid |
| 9 days | 1° Alk. | 7° Acid |
| 23 days | 4° Alk. | 7° Acid |
| 35 days | 5° Alk. | 7° Acid |
| 50 days | 5° Alk. | 7° Acid |

[1]Fuller's scale. Titrations made cold, using phenolphthalein as an indicator.

In another series of clover-juice cultures the reaction proceeded as far as 9° alkaline. A quantitative analysis of the ammonia content gave .0180%. If the 9° alkalinity is calculated as being entirely due to ammonia, it would be equivalent to .0153%, the difference between this and the quantitative determination being within the limit of experimental error.

Cultures growing on litmus-lactose agar caused the litmus to begin to turn blue within four days. After two weeks the blue coloration of the litmus had permeated the agar for considerable distance beyond the region of fungus growth, indicating the presence of an extra-cellular protein-splitting enzyme resulting in the formation of ammonia which causes the litmus to turn blue; also that this enzyme can diffuse to a considerable degree through the agar.

After about a month the fungus usually stops growing in the clover juice. In order to determine the cause of this the following experiments were performed:

Clover juice liquid upon which the fungus had been growing for five weeks was made sterile by passing first through paper and then through a sterile Berkfeld filter. The reaction of this liquid was 5° alkaline. To a 20 cc. portion of this was added 5 cc. of a sterile 10% glucose solution, thus making a medium with a concentration of 2% sugar. This was then heavily inoculated with spores from a 12 day old culture. A similar inoculation was made into the liquid to which no glucose had been

added. By the addition of sterile normal NaOH solution the reaction of portions of the original uninoculated medium was adjusted to 5° and 12° alkaline respectively. Twenty-five cc. of each of these was inoculated from the same culture as the other two. The following table gives the results:

Table 9.

Effect of Reaction upon Growth, etc. Test with Filtered Extracts.

| | 7 days | 12 days | 21 days |
|---|---|---|---|
| Culture liquid plus 2% glucose | – | – | – |
| Culture liquid no glucose | – | – | – |
| Sterile clover juice medium, 5° alkaline | + | ++ | ++ |
| Same—12° alkaline | + | ++ | ++ |

–, no growth; +, fair growth; + +, good growth.

From the above results it is evident that neither the alkalinity nor the absence of food are the causes of the discontinuance of growth. The accumulation of metabolic by-products is the probable cause of the retardation of growth.

*Changes in Carbohydrate Media:*

Neither acid or gas is formed in fermentation tubes when the fungus grown in 2% glucose, 2% maltose, or 2% saccharose. The quantity of growth in these solutions is fair, and if any acid is formed, the amount is so small that its presence cannot be detected with litmus paper.

*Anaerobic Growth:*

A Lavaran tube was used for growing the fungus in the absence of oxygen. In one arm of the tube clover juice agar which had been boiled for several minutes to drive out the air was poured and slanted. When solidified this was at once inoculated. In the other arm of the tube pyrogallic acid and KOH solution were placed, and the mouths of both tubes quickly sealed with rubber stoppers which were then heavily coated with paraffin. Within two weeks the first signs of growth usually appeared. From that time on growth proceeded slowly with light spore formation between the fourth and fifth week. This experiment was repeated several times with the same results. It is extremely unlikely that a perfect anerobic condition was present inside the tube, since it is possible that the agar upon cooling absorbed sufficient air for the growth of the fungus. At all events the fungus can grow, though slowly with as meager supply of free oxygen as the average anaerobic bacterium.

TEMPERATURE RELATIONS.

This series of temperature studies was made by inoculating two tubes each of corn meal agar, clover agar, and clover juice and keeping incubators at the various temperatures.

The lowest temperature at which observations were made was 6°C[1]. A light aerial mycelium appeared within four days. Some spores though comparatively few in number were produced in 7-9 days. At the same time a healthy plant inoculated with the fungus was placed in the incubator beside the culture tubes. The first signs of the disease appeared on the fourth day, and the typical spots bearing a few spores were observed on the eighth day. The humidity in this incubator varied from 85 to 98% of saturation. The light was very diffused, entering the incubator through a glass door facing a north window. Although the temperature was low, conditions favored the fungus more than the plant, which was practically dormant. The high humidity favored the germination of the spores, hence, infection was to be expected.

At 9-12°C. (ice box), the fungus grew slowly, making about the same amount of growth as at 6°C.

At room temperature, (20-24°C.), the fungus made its optimum growth. At this temperature all culture studies were made.

At 30°C., growth was a little retarded. The spore development was fair.

At 33-34°C., growth appeared like that at 30°C., but microscopic examination showed that no spores were formed. As occasional young conidum appeared at this temperature, but on the whole spore formation was retarded. If cultures kept at this temperature were removed to room temperature spores developed within one to three days even after they had been kept at the higher temperature for 19 days.

At 37°C., growth proceeded no farther than the germination of the spores. Removal to room temperature brought about normal growth even if the cultures were kept in the incubator for eleven days. This temperature may be considered as the inhibiting one.

*Thermal Death-point:*

Duplicate tubes of liquid and agar media were inoculated with one-tenth cc. of a water suspension of spores and heated at a given temperature carefully controlled in a water bath, during a period of ten minutes.

No growth developed in any of the cultures heated at 60°C. for 10 minutes. After 10 minutes at 56°C., growth in all media was normal. With exposure for 10 minutes at 57 and 59 C., growth was present but much retarded. Microscopic examination showed many ungerminated spores. The thermal death-point, therefore, must lie between 59 and 60°C. for 10 minutes, but many spores are killed at that time limit between 57 and 59°C., though some always seem to survive. This experiment was repeated twice with the same results.

[1]This temperature was secured in the constant temperature ice box described by Coons (1916), p. 727.

*Effect of Dry Heat:*

In order to determine the effect of dry heat a large test tube was used, with a thermometer inserted through a rubber stopper so that the bulb was suspended about 5 mm. above the bottom. The tube was heated in the water bath until the air within reached the desired temperature as was indicated by the thermometer. Three cover slips upon which a drop of spore suspension had been previously placed and dried over $CaCl_2$, were dropped into the tube and were held at the constant temperature for 10 minutes. It was found that the spores survived even when heated at 75°C., for 10 minutes.

*Thermal death-point of the Germinated Spores:*

Spores in the process of germination are known to be more sensitive to high temperatures than ungerminated spores, because of their weakened condition. This is the principle involved in the Tyndal method of fractional sterilization.

Clover juice cultures 34 hours old were heated (in triplicate) for 10 minutes in the manner before described. An additional thermometer immersed in the tube of clover juice was kept in the basket along with each set of culture tubes, and the time required to raise their temperature from that of the room to that of the bath, determined. This varied from two to two and one-half minutes and was not considered. After heating, the tubes were immediately cooled by plunging into ice water. The thermal death-point of these germinated spores was found to lie between 45 and 48½°C. for 10 minutes. Within 34 hours, it is quite certain that all of the viable spores had germinated, thus eliminating the possibility of growth, after heating, of any ungerminated spores. In the check experiment it was found that ungerminated spores heated in clover juice at 48½°C. were not killed even after an hour's exposure.

RELATION OF HUMIDITY TO GERMINATION.

Lesage, (1895), gives a method for determining the minimum humidity requirements for the germination of the spores of *Penicillium glaucum.* This method has a wide adaptibility, and should prove valuable in dealing with parasitic fungi. A similar method was used for determining the humidity requirements of *Macrosporium sarcinaeforme.*

The principle involved is that the saturation of air above a given solution varies inversely as the concentration of the salts dissolve therein. For NaCl the formula

$$1 - n\,a$$

was deduced, where *1* equals 100% of saturation, *n* the number of grams of salt, dissolved in 100 cc. of water, and *a* is a constant, which for

NaCl is .00601. The humidity is said to remain constant no matter how much the temperature may vary.

NaCl solutions of various concentrations were placed in dishes 5 cm. in diameter and 4 cm. deep (with the cover on). One-tenth of 1 cc. of a sterile distilled water spore suspension was dropped on the under side of the cover, and then dried *in vacuo* over $CaCl_2$. The cover was then placed over the dish of salt solution and sealed with vaseline, the distance between the surface of the solution and the dried spores being 2 cm. The dishes were kept in an incubator at 25° C. in order to prevent condensation of water upon the spore bearing surface, such as might take place with fluctuations in temperature. Examinations were made from time to time under the low power of the microscope, germination being thus readily observed. The following table gives the results of three sets of experiments:

Table 9.

Humidity Requirement for Germination of Spores.

| No. gms. NaCl in 100 cc. water. | 0 | 5 | 10 | 11 | 12–35 |
|---|---|---|---|---|---|
| % Humidity | 100% | 97% | 93.4% | 92.8% | 92.2-79% |
| Set 1 | 12 hr. | 18 hr. | 36 hr. | — | — |
| Set 2 | 10 hr. | 12 hr. | 48 hr. | 6 days[a] | — |
| Set 3 | 16 hr. | 24 hr. | 76 hr. | — | — |
| Avg. | 12.67 | 18 | 53.3 hr. | — | — |

[a] Only a few spores germinated. Probably accidental.

From the above results it is evident that the minimum amount of moisture required for germination lies between 92.8 and 93.4% of saturation, and that the time required for germination varies inversely as the percentage of humidity[1].

The spores germinating in the more humid air appears to be hygroscopic, judging from the thin enveloping ring of water visible under the microscope. The germ tubes were also hydrotropic, projecting out into the moist air rather than adhering to the surface of the glass as in the case when they are germinated in a hanging drop.

[1]The results obtained by Lesage for *P. glaucum* are of interest for the sake of comparison. It is evident that this common mold has a humidity requirement far below that of *M. sarcinaeforme*.

Showing interval in days elapsing before germination when spores of Penicillium are kept in moist chambers over various solutions of sodium chloride.

| n | 0 | 21.5 | 23.5 | 26.5 | 30-33.5 |
|---|---|---|---|---|---|
| Interval | 1 da. | 6 da. | 9 da. | 11 da. | No germination after 171 days. |

Quoted from Davenport (1908). Experimental Morphology, p. 351.

### RESISTANCE TO DESICCATION.

The spores of *M. sarcinaeforme* can withstand a long period of desiccation. As previously remarked, the material from which the fungus was first isolated was 18 to 20 months old. Furthermore, it had been kept in a drawer where the temperature for hours at a time reached 65° C, (drawer was over a steam radiator). In November, 1915, the fungus was again isolated from material collected in the fall of 1914. Desiccated spores kept on a cover glass for 9 months were found to be viable.

The multicellular structure of the spore and its large size give it more opportunity to withstand desiccation. There is always a possibility of at least one of the many cells of the spore to survive the desiccation process, thus providing for the further propagation of the fungus.

In the case of bacteria, Staphylococci (in clusters) are known to be far more resistant to desiccation than Diplococci or Streptococci. Again the presence of Sarcinae in dust would indicate that its packet-like structure (to which the spore form of *M. sarcinaeforme* is analogous) is an important factor in its resistance to desiccation.

### LIGHT RELATIONS.

To determine the light relations of this fungus, four different kinds of media were inoculated in duplicate, wrapped in black paper, and put away in a dark cupboard. A similarly inoculated set of cultures were kept in the light. Two weeks later the tubes were examined and the amount of growth in both was found to be about the same. This fungus does not, therefore, show marked reaction to light.

*Effect of Direct Sunlight:*

The usual method of determining the toxic effect of sunlight upon a fungus is to place a petri dish containing the freshly poured culture, in direct sunlight for various lengths of time.

Discs of filter paper, 1 cm. in diameter were cut with a cork borer, a pin run through each, near the edge, and then dry sterilized. A drop of spore suspension was then placed upon the upper side of each disc and the water permitted to evaporate rapidly in vacuo in a desiccator containing $CaCl_2$. The discs were then mounted in a horizontal position by sticking the pins into a cardboard box, and then placed in the direct sunlight. At intervals of 10 minutes three of these discs were removed and each dropped into a tube of clover juice medium. The discs were shifted at times, so as to be constantly in the direct rays of the sun. This experiment was run June 28th, 1915, between 9:30 and 11:40 A. M. The temperature in the direct rays of the sun varied from 29 to 34°C. Within the usual time growth appeared in all the tubes showing that

the fungus spores can tolerate direct sunlight for at least a period of two hours and ten minutes. Several cases of contamination occurred, but these did not interfere with the results, as the experiment was run in triplicate.

### EXPERIMENTS DEALING WITH THE TOXIC SUBSTANCE PRODUCED BY THE FUNGUS.

*Historical Introduction:*

Our knowledge of that biological adjustment which makes an organism parasitic, and restricted, quite often, to only one host, is as yet very indefinite. Research in this vast field is only in the beginning stage, though some fundamental studies have already been made.

DeBary's (1886) epoch making research with *Sclerotinia libertiana,* was probably the first fruitful attempt to determine the nature of parasitism. Those who followed him proceeded along the path he opened. Most of the investigations seem to have been directed toward the cytolytic activities of the fungus upon the host. While the demonstrations of the destruction of the cell wall or its cementing substance by lytic enzymes may be considered the first work necessary in the study of parasitism, such studies fail to explain the subsequent killing and disorganization of the protoplasts. It must also be remembered that the cellulose walls are for the most part non-living, and again, these walls being porous would not be marked impediment to any osmotic or toxic activity of fungus secretions upon the plasma membrane. Nor does the fact that specific enzymes have been demonstrated both within the cells of certain fungi and in the dead tissues of the hosts which they parasitize, explain what actually causes the killing of the cells. DeBary has shown for *S. libertiana* that the fungus must kill the host cells in advance of growth, and that it is the disintegration products of the dead cells which provide food for the fungus. He also suggested that the oxalic acid found in connection with the fungus might be the toxic principle. Among the contributions which followed DeBary's we find Marshall Ward's dealing with a Botrytis disease of lily (1888). He confirmed DeBary as to the presence of cytolytic enzyme, but contributed nothing further toward our knowledge of the toxic principle. Later, follow in quick succession, the work of Behrens (1898), Nordhausen (1899), and Smith (1902), dealing with the parasitic nature of *Botrytis cinerea.* Smith concluded that oxalic acid is the toxic principle. However, Brown (1915), in a recent paper, has proven conclusively that neither oxalic acid nor oxalates contribute to the lethal principle of the fungus extract. Brown has also made marked advance in that he has established a quantitative basis of

experimentation. The nature or origin of the lethal principle is as yet unknown.

In the realm of bacterial diseases of plants, the work done has similarly been confined to the enzymotic studies. Jones (1909), and Van Hall (1908), have demonstrated the presence of lytic enzymes in liquid culture media in which the bacteria has been growing. There is little or no contribution explaining the cause of the death of the cells.

The series of experiments which follow were undertaken to determine whether the metabolic by-products produced by *M. sarcinaeforme* in the culture medium, have any toxic effect upon the leaf tissue of red clover; and, if such a toxic substance were present, to determine its nature. Along with this, tests were made, using extracts from the fungus whose by-products were studied.

Concerning the technique involved, the author believes, that in at least one respect, he is free from a criticism which applies to some contemporary work. In studying the toxic activities of various extracts most of the experimentors have used sections of tissues or entire organs detached from the living plant. While it seems extremely likely that

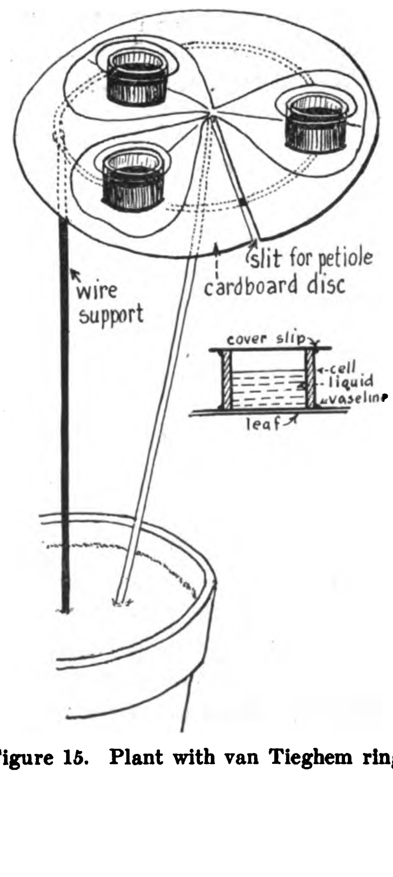


**Figure 15. Plant with van Tieghem rings.**

the tissue remains alive during the entire experiment, yet the cells are subject to those serious organic disturbances as a result of the separation from the main plant or organ, as well as oxidation, etc.

The author has used a means of applying the extract to be tested directly to the leaves of the living plant without detaching them. The method employed was as follows: A cardboard disc about 5 cm. in diameter, with a slit extending from a small hole in the center to the circumference, was slipped around the petiole of the clover leaf near its base. This disc was then supported upon a horizontal wire ring bent at right angle to a vertical piece of wire stuck in the ground. As a retainer of the liquid to be tested a Van Tieghem cell was sealed with vaseline upon the upper surface of the leaflet. The weight of the cell served to hold the leaflet in a flat horizontal position upon the cardboard disc. The liquid was then dropped into the cells with a pipette, and cover slips smeared with vaseline pressed down upon the upper edges in order to prevent evaporation. (Fig. 15.) This arrangement retained the liquid for a long time without drying out. In order to examine, macroscopically from time to time, the effect upon the leaflet, (where the liquid was dark colored or non-transparent) the liquid was drawn up into a pipette with a fine point, replaced if necessary and the cell again sealed. That the vaseline has no effect upon the leaf tissue nor upon the liquids tested, has been determined by the use of proper controls with each experiment.

*Tests of Metabolic By-Products:*

A clover-juice culture 75 days old was used. The fungus growth, which consisted of a heavy mycelial mat was removed by first passing the culture liquid through a filter paper and then through a sterile Berkfeld filter. Transfers were at once made to agar in order to determine later whether or not the filtrate was sterile, although microscopic examination at the time failed to reveal the presence of any fungus or bacterial cells.

With a sterile pipette, a small quantity of filtrate was added to each cell arranged as above described, (.4-.5 cc. reaching to within a few mm. of the top of the cell) and sealed with a cover slip. The test was made upon both wounded and unwounded leaves. In wounding, the epidermis was lightly scratched with a fine-pointed, sterile needle, care being taken not to puncture the leaf. Two or three of these scratches, 3 to 4 mm. long, were made in the center of the area enclosed by the cell. Such scratches could barely be seen with the naked eye. In the table below each number corresponds to the three individual leaflets of a single leaf; hence making the test in triplicate for each number.

Table 10.

Toxic filtrate on Clover Leaflets.

Test with Wounded and Sound Leaves under Van Tieghem Cells.

| | | | Results. | |
|---|---|---|---|---|
| Leaf. | | Liquid added. | 34 hours. | 56 hours. |
| 1-5 | Wounded | Filtrate from old culture | 1, 2, 3, 5, blackened about wound. 4, positive blackening but less than others | Entire area enclosed in cells discolored |
| 6-8 | No wound | Ditto | No reaction | No reaction |
| 9-11 | Wounded | Sterile[1] clover juice (uninoc.) | Slight discoloration at scratch | No change |
| 12-14 | No wound | Ditto | No reaction | No reaction |
| 15 | Wounded | No liquid added | Slight discoloration at scratch | No change |

[1]This was taken from the same lot of culture medium which was used for the above culture.

It may be stated here that while contamination of the liquid in the cells was to be expected, there was no evidence of fungus growth at the end of the 56 hour period. A hanging drop of the sterile clover juice used as a check showed numerous bacteria, but these apparently had no effect even upon the wounded leaflets. The filtrate which caused the discoloration contained but a few bacteria. It is therefore reasonable to suppose that the contaminating organism played no part in the discoloration of the tissue. Microscopic examination of the discolored tissues did not reveal any fungous growth and no growth appeared on the agar to which transfers had been made from the filtrate. Four days after the first series of tests were started a similar series was set up, using the same filtrate as before which in the meantime had been kept sterile in the filter flask. In this series, practically the same results as before, were obtained. From this experiment there seems no doubt that the clover pathogene produces a substance which can kill the wounded clover leaves.

*The Nature of the Toxic Substance:*

The purpose of this experiment was, (1) to determine whether the toxic substance is an enzyme; (2) whether any toxic substance is secreted within the fungus itself; (3) a repetition of experiment 1; and (4) the effect of heating upon toxicity.

In this case a clover-juice culture 32 days old was used. The superficial fungous growth was removed by passing through a filter paper, thereby obtaining a filtrate of 80 cc. volume. To this was added 800 cc. of 95% alcohol, and the precipitate thus formed allowed to settle for one hour. This flocculent, brown precipitate was filtered off and more

alcohol added to the filtrate. It was washed several times with alcohol, dried in a desiccator, and redissolved in 60 cc. of distilled water. Alcohol was again added to make a concentration of 80% and the resulting precipitate together with that formed in the first filtrate, filtered off. After washing and drying it was again dissolved by repeatedly passing 80 cc. of distilled water through the filtrate. To this was added 0.6 cc. of toluol as a preservative. For convenience in tabulating the data which follows, this will be called preparation "A."

The bulk of the alcoholic precipitate consisted of protein and brown pigment matter. It was assumed that any enzyme which might be present in solution would be precipitated by the alcohol. If any white enzymic precipitate was present, there was no macroscopic method of determining this, because of the presence of the brown colored impurities, which the above treatment failed to remove.

Preparation "B":—The fungus growth from a clover juice culture of the same age as the preceding was filtered out through paper and then through a sterile Berkfeld filter. To this filtrate 2% toluol was also added.

Preparation "C":—The fungus growth which had been removed from the above cultures and that from two others of the same age was washed in a little running tap water and the superficial moisture removed by pressing gently between sheets of filter paper. In order to insure rapid and thorough drying, the fungous growth was then placed in a desiccator containing $CaCl_2$ and the air exhaust attached. When desiccated it was ground with clean quartz sand until practically no entire spores or mycelial cells remained. This ground mass together with 60 cc. of water plus 2% toluol was put into a bottle and agitated for one hour in the shaking machine. The extraction was prolonged for 18 hours more with an occasional shaking by hand. The sand and fungus particles were removed by filtering through cotton, and the filtrate used for the experiment.

Preparation "D":—Sterile clover juice medium plus 2% toluol.

These preparations were tested upon a lot of clover plants all of which had been planted in the greenhouse at the same time, from the same lot of seeds. They were all in normal healthy condition, and well watered during the entire experiment. The Van Tieghem cell arrangement, above described was used; likewise all other technique was the same. Each number again refers to a leaf with each of the three leaflets bearing a cell containing the same preparation.

The following table explains the procedure and the results after 48 hours:

Table 11.

Toxic Effect of Various Liquids:

Van Tieghem Cells on Clover Leaflets.

| No. | Liquid tested. | Treatment of leaflet. | Results after 48 hours. |
|---|---|---|---|
| 1 | "A" Enzyme (?) | Wound | No change |
| 2 | "A" Enzyme (?) | Wound | No change |
| 3 | "A" Enzyme (?) | No wound | No change |
| 4 | "A" Enzyme (?) | No wound | No change |
| 5 | "A" Enzyme (boiled)[a] | Wound | No change |
| 6 | "A" Enzyme (boiled)[a] | No wound | No change |
| 7 | "B" Filtrate from fungus culture liquid | Wound | Complete discoloration |
| 8 | "B" Filtrate from fungus culture liquid | Wound | Complete discoloration |
| 9 | "B" Filtrate from fungus culture liquid | Wound | Complete discoloration |
| 10 | "B" Filtrate from fungus culture liquid | Wound | Partial discoloration |
| 11 | "B" Filtrate from fungus culture liquid | Wound | Complete discoloration |
| 12 | "B" Filtrate from fungus culture liquid | No wound | No change |
| 13 | "B" Filtrate from fungus culture liquid | No wound | No change |
| 14 | "B" Filtrate from fungus culture liquid (boiled)[b] | Wound | No change |
| 15 | "B" Filtrate from fungus culture liquid (boiled)[b] | Wound | No change |
| 16 | "C" Fungus extract | Wound | No change |
| 17 | "C" Fungus extract | Wound | No change |
| 18 | "C" Fungus extract | Wound | More discoloration than in others of same treatment |
| 19 | "C" Fungus extract | No wound | No change |
| 20 | "C" Fungus extract | No wound | No change |
| 21 | "C" Fungus extract (boiled)[b] | Wound | No change |
| 22 | "C" Fungus extract (boiled)[b] | No wound | No change |
| 23 | "D" Sterile Clov. juice | Wound | No change |
| 24 | "D" Sterile Clov. juice | Wound | No change |
| 25 | "D" Sterile Clov. juice | Wound | No change |
| 26 | "D" Sterile Clov. juice | Wound | No change |

a Liquid merely heated to boiling.
b Boiled before toluol was added.

A glance at the results in the above table will show that if any enzyme was precipitated by the alcohol, it had no effect upon the leaves, wounded or unwounded. The same holds true for the extract of the fungus growth. However, the results of the preceding experiment are confirmed by the action of the filtrate "B." It is also evident from the control that the addition of toluol as a preservative has no injurious effect upon either the host of the filtrate, but that boiling inactivates the toxic principle in the filtrate.

When the filtrate was titrated, it was found to be 9° alkaline (Fuller's scale). A test with Nessler's solution gave indication of the presence of ammonia, which upon quantitative analysis was determined as .018% $NH_3$. It was thought that the ammonia might be the cause of the discoloration of the tissue. To determine this, leaves both wounded and unwounded were subjected to the action of concentrations of ammonia equaling .01%, .02%, and .05% respectively, using the same setup as in the preceding experiments. No signs of discoloration appeared within three days, proving that at least the ammonia alone is not the toxic principle.

This series of experiments was later repeated. For this purpose, clover juice cultures similar to those tested before, were used. These were inoculated October 11th, just six weeks after the cultures used in the preceding experiment were inoculated. The filtrate was prepared as before, at intervals when the cultures were four, five, and seven weeks old. In no case, however, were the leaves in any way discolored as a result of their contact with these filtrates. Likewise the filtrate from a culture in Dunham's peptone solution had no effect upon the leaves, although it contained considerable ammonia.

A probable cause for this apparent loss in toxicity was later discovered. It was observed that inoculations which were made from time to time during the months of October and November failed to produce positive infection. Inoculations were made repeatedly under a variety of conditions but without success. It was therefore evident that the fungus had lost much, if not all, of its virulence. In order to make certain of this, a fresh strain of the fungus was isolated from material collected during the summer. Four sets of red clover plants of the same stage of growth were selected. These were then inoculated with both the old and the new cultures as shown in the following table:

Table 12.

Test of Old and New Isolation Plants Under Bell Jars with Saturated Atmosphere.

| Set. | Culture. | Treatment. | Condition after 7 days. |
|---|---|---|---|
| 1 | Old | Sprayed with suspension of spores | No infection |
| 2 | Old | Mass of fungus growth placed upon leaves and covered with cotton | Discoloration only under inoculum[a] |
| 3 | New | Sprayed with suspension of spores | Abundance of typical infections |
| 4 | New | Mass of fungus growth placed upon leaves and covered with cotton | Abundant typical infections |

a Spores show germination sprouts, barely enter leaf, then stop growing.

This comparative test of the two cultures was repeated under more exact conditions as follows: Two pots of red clover, each containing numerous plants, all planted at the same time, from the same lot of seed were used. One pot of plants was sprayed thoroughly with a spore suspension from the old culture, and the other was sprayed with a suspension of spores from the new culture. In both cases, the quantity of spores sprayed upon each plant, was made as nearly as possible the same. Each pot was kept under a separate bell jar, and the atmosphere maintained in a saturated condition. The plants sprayed with spores from the new culture began to develop the disease upon the fifth day after inoculation. After 10 days, these plants were heavily infected, while those inoculated with spores from the old culture showed only a few isolated cases of poorly developed spots. Examination of some of the uninfected leaflets of the latter plants revealed many spores on the surface which had not entered the host. The difference between the degree of infection caused by the old culture and the new culture is illustrated by Plates XV and XVI which were taken after 10 days.*

From the results of such a comparative experiment, we cannot but conclude that the old culture has lost much, if not all, of its virulence. This attenuation may be due to the prolonged saprophytic habit which the fungus has been subject to while growing on culture media. It is commonly asserted that parasitic fungi lose their virulence when kept in culture for a long time, but exact experimental evidence is not at hand.

In view of the apparent attenuation of the fungus virulence, the coincident failure of the filtrate from culture liquid to have any effect upon the leaf tissue, may be explained. Time has not permitted a comparative study of the filtrate from both the old and the new cultures. Such a test would be the only way of determining definitely the relation between the loss in virulence and the toxic activity of the by-product of the fungus.

Perhaps conclusions are not justified on the basis of a few experiments which are only preliminary. The following is a summary of the experiments:

1. The fungus secretes a substance in the culture medium, which discolors and finally kills the wounded leaves.

2. This toxic substance is inactivated by boiling.

3. The ammonia present in the culture liquid is not, at least by itself, the toxic principle.

*Dr. Coons informs me that he has since repeated the experiment with similar results.

4. Any enzyme which can be separated from the culture liquid by precipitation with alcohol, etc., is not the toxic principle.

5. An extract from the mycelium which produces the toxic substance in the culture liquid, has no toxic effect upon the leaves.

6. The original isolation began suddenly to lose its virulence. New isolations were virulent.

7. At the same time the filtrate from the attenuated culture lost its toxicity.

We have to deal in the study of this organism with a pathogene in which the toxic principle is more evident than any lytic agent. This toxic principle is either an excretion from the mycelium rather than an integral part of it, or else it is the result of the cleavage of the culture solution. At all events the toxic substance is able to produce a blackening quite like that produced in the normal course of the disease. It is probably not an enzyme. It is somewhat thermolabile. Although occurring in a medium strongly alkaline with ammonia, the failure of ammonia solutions of similar alkalinity to produce like results, seems to indicate that the ammonia is not responsible for the toxicity. Associated with the success or failure of the toxic substance, we find respectively virulence or attenuation.

### METHODS OF DISSEMINATION.

The possible methods of dissemination of the fungus were deduced from extensive field observations under control conditions. There are two phases to the process by which a plant pathogene may be disseminated: First, the translocation of the causal agent; second, the presence of those conditions which are conducive toward the entrance of the host by the organism. In the experiments which follow, these two factors were considered wherever possible.

*Soil:*

In the dissemination of any disease, the soil merely plays the part of a harboring agent. To determine whether the plants can be infected directly from the soil which has grown a diseased crop, the following experiment was performed:

The upper two or three inches of soil from a field in which badly diseased plants were growing, was selected. This soil, upon examination, was found to contain bits of dried, diseased leaves. A little of the soil was also shaken in water, which was then removed and centrifuged. Spores of *M. sarcinaeforme* were found in the sediment, thus making positive the presence of the fungus. In this soil, red clover seed which

had been previously disinfected by treating with 1:1000 $HgCl_2$ for 10 minutes, and washing in three changes of sterile water, were planted. The soil was watered every day from a beaker. The seedlings which appeared above were not infected even after they had reached a height of 6 cm. The plants at this stage were then separated into two groups. The first group was watered as before (from a beaker), while the second group was watered from above with a hose, the water simulating more or less the falling of rain. The soil was thus splashed up onto the lower leaves. One week later the plants so watered were infected, while those watered from below were not.

The correlation between the spread of the disease toward the upper parts of the plants in the field above described, and the precipitation during the month of June, is striking, and corroborates what was proven by experiment. The total precipitation from June 1st to June 10th inclusive was 0.46 inches, or a daily average of 0.046 inches. The total precipitation from June 11th to June 21st inclusive was 3.28 inches, or a daily average of 0.298 inches. Field observations showed that the spread upward was most rapid between the last mentioned dates.

From this experiment it is evident that while the soil and trash from a diseased crop harbor the causal organism, they are not the only factors in the production of infection. Splashing by rain is regarded as a translocating agent. The rain, of course, also furnishes the moisture necessary for germination after the spores have reached the plant.

Field observations made during the course of this study seem to corroborate the result of the above experiment.

*Seed:*

The most common agency introducing plant pathogenes to the field, is the seed. Reference has already been made to the statement of Milburn (1915) as to the presence of the fungus on the seed. Seed samples from the 1915 and 1914 crops were examined for the presence of the fungus. The fungus was not found growing upon any of the seed, as a parasite. However, by centrifuging for one hour at a high rate of speed, spores of *M. sarcinaeforme* were found in four out of nine samples so treated. Incidentally, a large number of rust (Uromyces) and other fungus spores were found. Some of the seed from samples containing disease spores were planted in sterile soil, the pot containing it being covered with a bell jar. None of those plants which came up developed any signs of the disease, even after six weeks. This negative result is not entirely conclusive, in that the experiment was not conducted upon a large enough scale. But it seems likely that the spore containing seed is merely a means of transferring the spores to the soil from which point, the infection takes place by splashing as has already been demonstrated.

*Dissemination and Rainfall:*

The active influence of rainfall as demonstrated by the transfer of the fungus by splashings of water from the soil has already been mentioned. The significance of the splashings in this connection is seen when periods following mist-like rains are compared with periods in which the rain was more abundant. The correlation between the amount of rainfall and the appearance of the disease in an uninfected field, was noted under the following circumstances: A second crop of red clover following a first crop which had been badly diseased, reached a height of 7-9 cm. without becoming infected. October 15th this field was carefully examined for the presence of the disease but nothing was found. On October 25th many of the lower leaves were found to be infected with the fungus. The weather reports for October indicate the following precipitations:

| | |
|---|---|
| Total precipitation, Oct. 1-15 .................... | 0.84 in. |
| Daily average, Oct. 1-15 ........................ | 0.021 in. |
| Precipitation, Oct. 17 ........................... | 0.06 in. |
| Precipitation, Oct. 18 ........................... | 0.80 in. |

The disease was found in the field October 25th, seven days from the last date. The heaviest rainfall between October 1st and 15th occurred on October 1st, but at this time the plants were hardly out of the ground. The heaviest rainfall of the month occurred on October 18th, and it will be noted that the disease appeared one week later. The heavy rain of the 18th was probably the cause of the splashing of the infected soil upon the plants, with the resulting infection.

*Experiments on Wind Dissemination of Spores:*

Discussion of the problem:—That the wind is more or less a factor in the dissemination of fungous spores has always been assumed, but little experimental work has been done to demonstrate this. The carrying of the spores of *Endothia parasitica* (Murr) And. has been suggested by several authors, but it remained for Heald, Studhalter, and Gardiner (1915) to prove this. They obtained spores in large numbers at a distance of 300-400 feet from the source of supply, and justify the conclusion that they may be carried much greater distances.

Probably the best way of determining the spore carrying capacity of wind of known velocity is by outdoor experiments with spore traps. This was the method used by the above mentioned authors. In the case of *M. sarcinaeforme,* however, this was impractical during the summer because of the general distribution of the disease. Any experiment under laboratory conditions is necessarily subject to interpretation because of the difficulty of creating a wind similar to that outdoors; also the absence

of altitude which outdoors gives an opportunity for upward sweep of the wind. Nevertheless the following experiments were performed.

*Field Experiments in Spore Dispersal:*

For this purpose a tube about 14.6 meters (48 ft.) long, 32.5 cm. (14 in.) high, and 30.5 cm. (12 in.) wide was constructed thus: The framework was made in three equal sections, using strips of yellow pine 2.5 cm. (1 in.) square. Each frame was then covered on the outside with wrapping paper and the seams thoroughly glued. The sections were set up outdoors in a horizontal position one meter above the ground and the ends joined together by covering with more paper. Since the wind at the time was blowing from the east, the tube was set up in an east and west direction. Petri dishes containing agar were then placed at 60 cm. (2 ft.) intervals on three boards about 5 meters (16 ft.) long, 15 cm. (6 in.) wide, and 1.25 cm. (½ in.) thick, and held in place by driving two-penny nails into the wood. The boards with the dishes of agar were then shoved into the tube so that they rested on the bottom framework. In this manner a means of catching spores at .6 m. intervals along the entire 14.6 meters (48 ft.) was obtained.

The dried spores used in this experiment were prepared in the following manner: The growth from a clover juice culture was removed and shaken with a little water in order to wash off many of the spores. The spores were then precipitated from suspension by centrifuging. They were then dried over $CaCl_2$ in vacuo, and kept in a tightly stoppered tube until ready for use. Just before using, those which were massed together in small dried lumps were ground lightly in a mortar.

The dried spores were slowly released into the east end of the tube through a small funnel inserted through a hole in the top side. This was done gradually, by rubbing a little at a time between the fingers and dropping into the apex of the funnel. Just inside of the west end of the tube an anemometer was placed so that the center of the wind receiving device was in line with the axis of the tube. The wind was permitted to blow through the tube 33 minutes from the time the first spores were released and then both ends of the tube were closed. The anemometer registered 34,476 meters during this time, which is equivalent to a velocity of 6.268 kilometers (3.93 miles) per hour. The reading given by the anemometer cannot be considered more than approximate, because the wind was constantly changing direction slightly, and the wooden framework inside the tube impeded, to a certain extent, the velocity of the air which passed through the tube.

The dishes were later examined microscopically and all except those located at the 3.6 m. (12 ft.), 4.2 m. (14 ft.), 6.7 m. (22 ft.), and 8.5 m.

(28 ft.) marks were found to contain spores. The distribution of spores was very uneven, but the fact that some fell into the dishes at the farthest end of the tube, is a positive indication that they were carried at least 14.6 m. (48 ft.). Minute black deposits of spores were also found scattered along the board upon which the dishes were placed. While it is possible that the spores remained suspended in the air over the entire length of the tube it is more likely that they fell to the bottom of the tube several times while in transit, to be lifted again by the wind and carried farther.

*The Rate of Fall of Spores:*

This assumption is not based entirely upon the uneven distribution of spores within the tube but also upon the results of the following experiment, whose purpose was to determine the velocity of spores falling in still air. For this purpose a glass tube 1.5 meters long and 4.8 cm. inside diameter was used. This tube was set up in a vertical position so that the lower opening rested about 1 cm. above the top of the table. The windows and doors of the room were closed, so as to exclude, as far as possible, any disturbing draughts. A petri dish containing agar was slipped under the lower opening of the tube. Dried spores were then released at the upper opening. Eight seconds after the release of the spores, the agar dish was quickly removed and another immediately slipped into its place. This second dish was no sooner in place than it was replaced by another. The second was removed 10 seconds, the third 12 seconds, the fourth 15 seconds and the fifth 20 seconds, after the release of the spores. Other dishes were placed under the tube at five-second intervals after the 20th second. Only in the first two dishes were spores found,—a large number in the first, and only a few in the second. It required, therefore, a maximum of about 10 seconds for the spores to fall a distance of 1.5 meters,—that is, the minimum velocity of a falling spore is roughly, about .15 meters per second. A velocity of 6.268 km. per hour is equivalent to 1.74 meters per second. In the 14.6 meter tube used in the preceding experiment about two seconds would therefore be required for the spores to fall from the top to the bottom,—a distance of 30 cm. A wind with a velocity of 1.74 meters per second would carry a spore a maximum horizontal distance of 2 x 1.74 m, or 3.48 m. before it fell to the bottom of the tube. Once having fallen there is no reason why a slight upward trend of the wind could not again lift the spore and carry it farther, provided of course, it were not already trapped or impeded by some obstacle.

*Conclusion:*

From these experiments, no definite assertion can, of course, be made as to how far the spores can be carried by the wind. However, the indications are that the spores of *M. sarcinaeforme,* though comparatively large and heavy might be carried a sufficient distance from their source to reach and infect other fields of red clover. Outdoors, where a much higher elevation is obtainable, this distance should be much greater than in the tube experimented with.

This point should be considered, however. Under field conditions, especially in damp weather, many spores fall to the ground and are caught by the wet soil or between the lower parts of the plants. Spores so situated would not, therefore, be in a favorable position for dissemination by the wind.

## CONTROL.

Any method of controlling the disease by the application of sprays is impracticable. Cavara's suggestion that the field be watched and the diseased leaves be removed as they appear, would, to say the least, be very difficult to follow where clover is grown on a large scale. The mowing of the young crop as soon as the disease appears, has been suggested as a remedy for several diseases of red clover. However, in the case of *M. sarcinaeforme,* the presence of the cut, diseased leaves in the field would be a source of infection to the new crop especially during rainy weather. The close relation to relatively high humidity indicates that well ventilated, well drained fields will suffer less from the disease than those in less favorable locations.

The value of seed disinfection is not at all known, nor is the role of the spores carried on the seed determined. The wide-spread distribution of the fungus, points to a seed dispersal of the fungus. The strong possibility of infection from volunteer clover or from the soil already infected from nearby fields by wind borne spores, makes any recommendation of seed treatment as yet unwarranted.

The ultimate solution of the problem of the control of this disease, and for that matter, the control of all field crop diseases, is the breeding of resistant varieties. In the case of Anthracnose of clover (Colletotrichum trifolii), this has been done. Bain and Essary (1906), in looking for a means for controlling this disease in Tennessee, began by selecting uninfected plants growing in a badly diseased field. From this selection, a strain of clover has been bred which is fairly resistent to the disease. The method of selection could probably be used in producing a resistant strain of red clover against any of its diseases. The author has seen occasional plants during the summer which were unaffected though growing in the midst of badly diseased plants.

It is noteworthy that alsike clover is far more resistant to most of the common diseases than is red clover. The possibility of hybridizing red and alsike clover in order to produce a disease resistant strain suggests itself. Certain cultural characters of alsike clover, as for example, the ability to grow upon "clover-sick" soil, might also be contributed to the improvement of the red clover strain.

### SUMMARY.

The disease caused by *M. sarcinaeforme* has so far not been carefully investigated. It is widely distributed in the United States and Europe. The loss it causes has not been estimated, but it has been responsible for local damage in various parts of the United States.

The fungus affects both the leaves and petioles,—on the former causing a typical concentrically marked leaf spot, on the latter brown to black linear streaks. The casual relation of the fungus *M. sarcineaforme* is proved. A description of the organism is given.

The morphology of the fungus studied by the author does not agree in all respects with the fungus described from Italy and Germany. Provisionally the name *Macrosporium sarcinaeforme* is retained.

The fungus enters the host usually between the epidermal cells of the leaf and attacks at first the parenchyma, proceeding intercellularly. Stomatal entrance was also observed. The cells are eventually killed and invaded by the fungus, which finally sends up hyphae between the epidermal cells (sometimes through stomata), on both sides of the leaf and produces spores. Typical spots develop within 5 to 7 days. As a result of infection the leaves eventually shrivel and fall to the ground.

Inoculations have not been successful upon either the old stems or the flower. The fungus readily attacks germinating seeds.

Red clover is readily infected by the fungus. Inoculations made upon local alsike clover has not been successful although Bain and Essary claim to have seen it on alsike clover associated with badly diseased red clover plants in Tennessee.

Inoculation experiments have also been unsuccessful on other legumes. The fungus on alfalfa called *M. sarcinaeforme* (U. S. D. A. Herb. specimens) has been found to be a different form from the *M. sarcinaeforme* on red clover from various parts of the United States.

The fungus causes a disintegration and collapse of the cells of the host. After penetrating the epidermis, the fungus advances intercellularly and intracellularly.

The diseased spots do not transpire. The injury to the clover is brought about by the unbalanced metabolism which leads to a depletion of the cell reserves.

The spores germinate readily in water. In clover juice large swellings at the base of the germ tubes appear, and new spores are formed within five to seven days. In five per cent dextrose solution the spores in some cases produce large, bud-like swellings resembling a young spore. This may be a trend toward an Alternaria habit.

The fungus grows well upon a large variety of culture media, without striking modification, except, perhaps, the dearth of spores on potato plugs, on which growth is otherwise well developed. Sugar seems to favor spore production.

In media containing nitrogen, ammonia is one of the end products of metabolism. No acid or gas is produced in glucose, maltose, and saccharose solutions.

The fungus grows at temperatures from 6° C. to 37° C., but at the latter temperature spores are not produced. The thermal death-point of the spores, wet heat, lies between 59° C. and 60° C. for 10 minutes. Dry spores are not killed by one hour's exposure at 75° C. (dry heat). Germinating spores are killed by exposure of 10 minutes to 45 to 48½° C.

The spores require an air humidity of 92.8 to 93.4% saturation before they can germinate. The spores will not germinate if the saturation is below 92.8%. The spores can withstand dessication for a long period of time, at least for 18 months, and probably very much longer.

The fungus grows equally as well in light as in darkness. The shaded lower leaves of the plants are more readily attacked than those well lighted.

In culture, the fungus produces a toxic substance. The results of this phase of the investigation have already been summarized on page 313. Marked attenuation was found in an old culture of the organism.

The disease-producing organism may spread from the soil to the plant as a result of splashing by the rain. The fungus probably lives over winter on the trash from a diseased crop. The ascent of the disease upward from the lower leaves seems to be co-ordinated with the amount of precipitation. The spores of *M. sarcinaeforme* have been found in red clover seed but not growing upon it. This is a possible means of disseminating the disease. Experiment has shown that the spores can be carried at least 14.6 meters (48 feet) by a wind with a velocity of 3.93 miles per hour, and it is very probable that outdoors, because of the higher altitude obtainable, they may be carried a greater distance, sufficiently far to reach and infect other fields.

The ultimate method of controlling this, and other clover diseases, must be on the breeding of resistant varieties.

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N. Dakota Agricultural College.

Editor's Note:—The salient points of this paper were presented at the XVIII Michigan Academy of Science meeting, but the manuscript was not presented for printing in the report of that meeting.

APPENDIX.

## Krakover Clover Leaf Spot.

*Formulae for Media used:*

*Nutrient dextrose agar.*

Plain nutrient agar plus 5% dextrose.

*Full nutrient sol. Kundson.*

1000 cc. water.
1 gm. $KNO_3$.
0.5 gm. $KH_2PO_4$.
0.25 g. $MgSO_4$.
0.002 g. $Fe_2Cl_6$.
5 g. cane sugar.

*Coons' synthetic Sol.*

Stock m/5
$MgSO_4$, 2.466 g. + 50 cc. $H_2O$.
$KH_2PO_4$ 1.36 g. + 50 cc. $H_2O$.
Asparagin 1.33 + 50 cc. $H_2O$.
Maltose 3.6 + 50 cc. $H_2O$.

For 100 cc. Synthet. Sol.

1 cc. of m/5 $MgSO_4$ and Aspar.
5 cc. of each of others.
88 cc. of water.

Steam 3 consecutive days.

*Coons' synthetic agar.*

Above solution plus 1.2% agar.

Steam 3 consecutive days.

*Rice.*

Add 3 volumes of tap water to 1 volume of rice.

Autocl. 15 lbs., 20 minutes.

*Corn meal.*

Corn meal with about equal volume of tap water.

Autocl. 15 lbs. 20 minutes.

*Potato plugs.*

Wash and peel a firm tuber. Cut into wedge shaped plugs, and place in tubes containing short pieces of glass rod and few cc. of water. Autocl. 20 lbs., 20 min.,

The following other vegetable plugs were prepared in the same manner as the potato: *Carrot, parsnip, sugar beet, red table beet.*

*Sorghum stems.*

Cut stems into pieces 2-3 inches long. Put into tubes containing little water. Autocl. 15 lbs., 20 minutes.

*Clover stems.*

Same as sorghum.

*Bean Pod.*

Mature pod of wax bean put in tube with little water. Autocl. 15 lbs., 20 minutes.

*Clover juice.*

200 g. of finely cut clover plants (leaves and stems) 1000 cc. tap water. Boil one hour, adding water occasionally to make up for loss by evaporation. Filter through cheesecloth and let stand a few hours until fine settlement settles to bottom. Filter through paper. Autoclave 15-20 lbs. for 15 minutes.

*Clover juice agar.*

Add 1.2% agar to above liquid. Clear and filter. Autocl. 15-20 lbs. for 15 minutes.

*Prune juice agar.*

120 g. prunes, 1000 cc. water. Boil in steamer two hours. Filter through cheesecloth. Restore to original volume.

12 g. agar. Boil in steamer two hours. Clear and filter. Autocl. 20 lbs., 20 minutes.

*Corn meal agar.*

Three tablespoonsful cornmeal, 1000 cc. water. Cook in double boiler at 60° C. for three hours. Decant, restore to original volume.

15 g. agar. Clear and filter. Autocl. 15 lbs., 20 minutes.

*Oat agar.*

75 g. Quaker oats, 1000 cc. water. Cook in double boiler two hours. Strain through cheesecloth, squeezing out the slimy matter.

10 gms. agar. Boil one hour. Autocl. 15 lbs., 20 minutes.

*Thaxter-Hard potato agar.*

250 g. sliced potato, 1000 cc. water. Cook one-half hour in steamer. Decant and restore to original volume.

20 g. of glucose.
30 g. of agar.
Cook in steamer three hours. Clear and filter.
Autocl. 15 lbs., 20 minutes.

*Nutrient glucose agar.*

40 gms. glucose, 1000 cc. distilled water, 3 g. of NaCl., 20 g. peptone, 5 g. beef extract, 30 g. of agar. Clear and filter.
Autocl. 20 lbs., 20 minutes.

*Plain nutrient agar.*

1000 cc. of water, 15 g. agar, 3 g. of beef extract, 10 g. peptone titrate. Clear and filter.
Autocl. 15 lbs., 15 minutes.

### EXPLANATION OF PLATES.

#### Plate XII.

The disease in various stages. (Leaves naturally infected). (Photo by G. H. Coons.)

#### Plate XIII.

Fig. 1—(a-g), showing various shapes of spores; (h), end view of spore, showing scar of attachment.

Fig. 2—Knob-like projections on some conidiophores.

Fig. 3—Secondary tip cell at (b).

Fig. 4—Relation of conidiophores to main mycelium.

Fig. 5—Spore giving rise directly to conidiophores bearing new spores.

Fig. 6—Typical spore and conidiophore.

Fig. 7—Typical leaf spot, showing concentric rings.

Fig. 8—Clover leaf, showing typical infection.

Fig. 9—Young leaf, with infection spreading to petiole (a).

Fig. 10—Leaf in last stages of disease, showing the shriveled condition of the leaflets (b, c). Note aggregation of small spots at (a).

Fig. 11—Germinating seed, with seed coat completely enveloped by the fungus growth; also the tip of the radicle attacked by fungus.

Fig. 12—Petiole infection, showing linear streaks.

Fig. 13—Young mycelium.

Figs. 14-18—Old mycelium found in culture.

Figs. 19-20—Toruloid mycelium, submerged in culture.

Figs. 21-29—Method of spore formation.

#### Plate XIV.

Figs. 1-6—Spore germination (in clover juice).

Fig. 7—Spore giving rise by budding to what appears to be a young spore (a).

Fig. 8—Spore germinating in water.

Fig. 9—Tip cell of conidiophore germinating after spore has fallen.

Fig. 10—Section through leaf (somewhat diagrammatic), showing how the tissue is completely disintegrated and invaded by the fungus. Note fungus spreading into healthy tissue at edge of spot.

Fig. 11—Early stage of infection; mycelium emerging through stoma.

#### Plate XV.

Plants sprayed with an old attenuated culture. Ten days. (Photo by G. H. Coons.)

## Plate XVI.

Plants sprayed with a newly-isolated virulent culture. Ten days. (Photo by G. H. Coons.)

### EXPLANATION OF FIGURES.

Fig. 14—Simple potometer.

Fig. 15—Plant with Van Tieghem rings.

## LEGENDS.

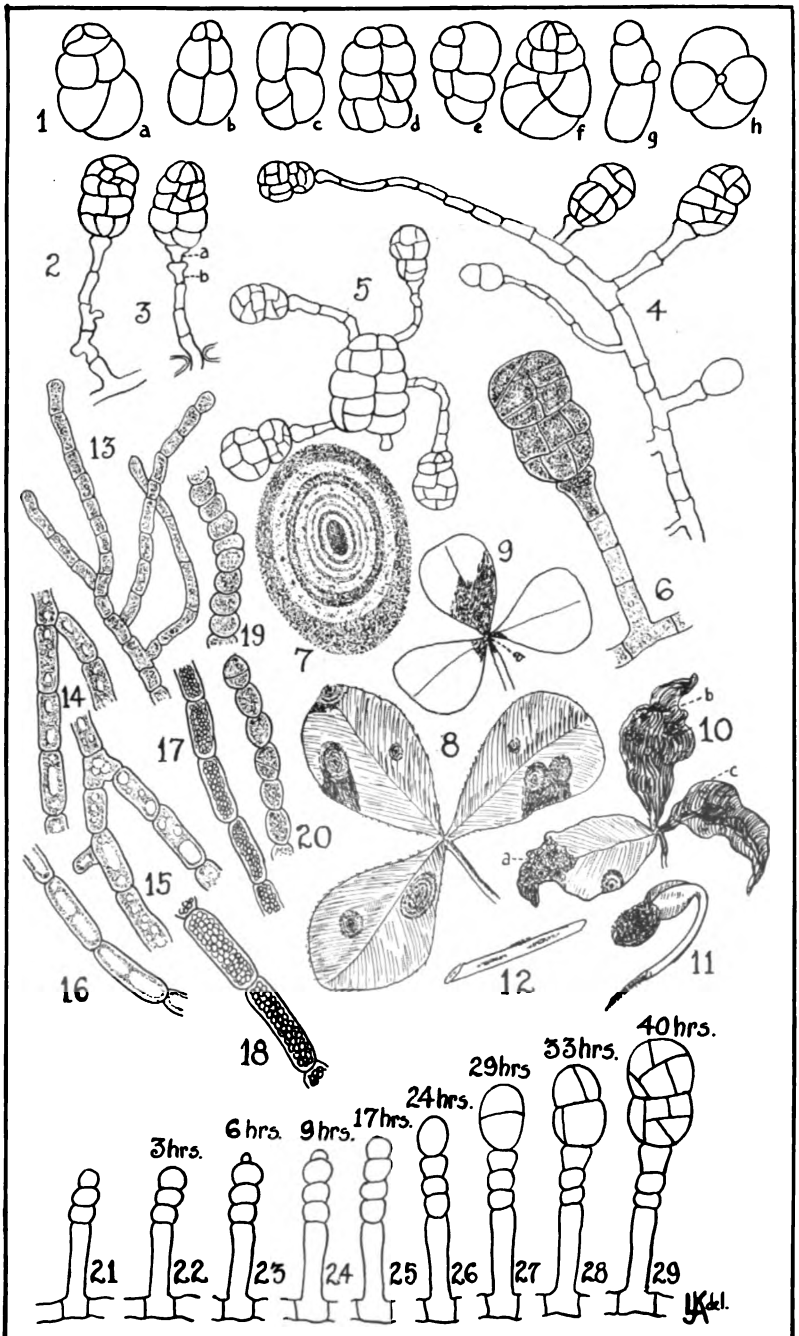
Plate XII. The clover leaf-spot disease in various stages. (Leaves naturally infected.)

Plate XIII. The clover leaf-spot fungus and its effect on the leaf. (29 figs.)

Plate XIV. The clover leaf-spot fungus and its effect on the leaf. (11 figs.)

Plate XV. Plants sprayed with an old, attenuated culture. 10 days.

Plate XVI. Plants sprayed with a newly isolated, virulent culture. 10 days.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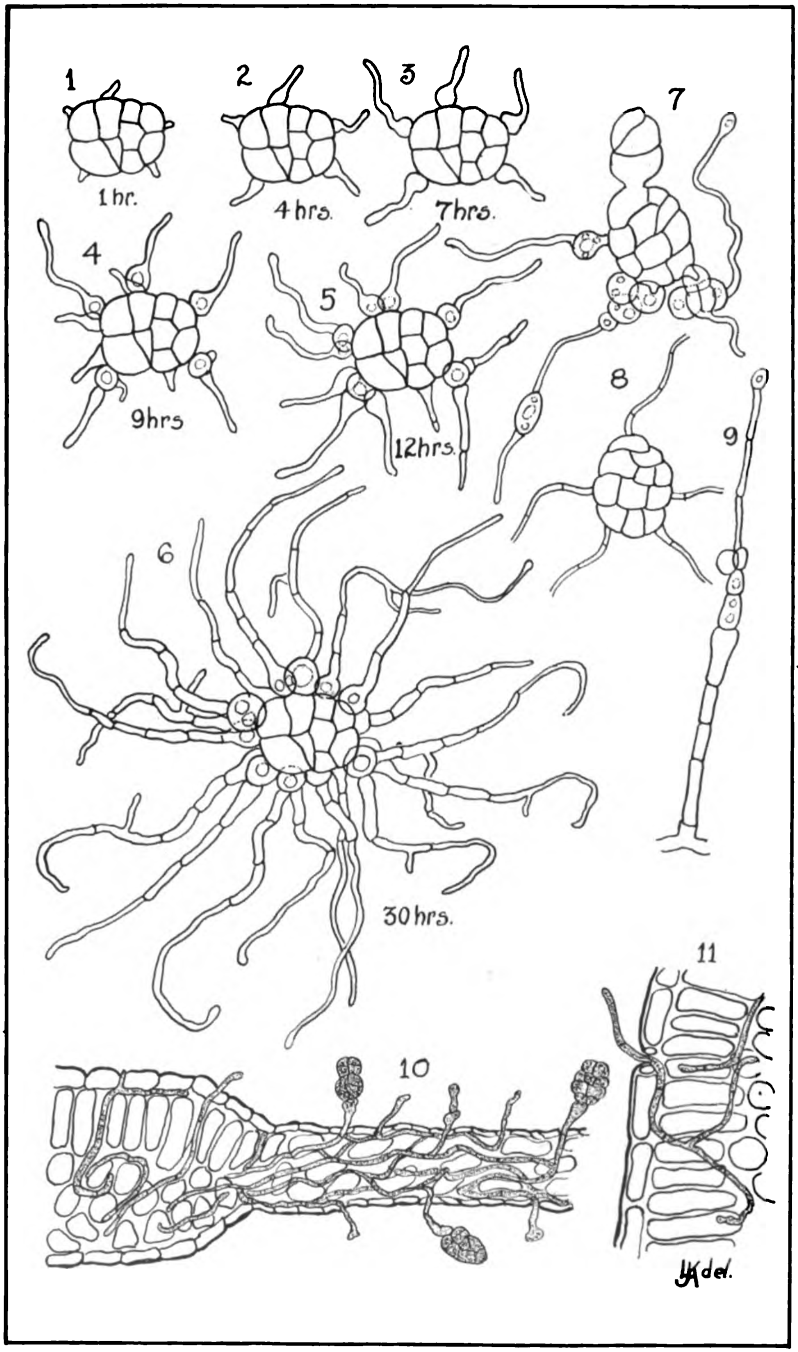
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# POLYEMBRYONY IN *QUERCUS ALBA*.

BY LE ROY H. HARVEY.

Polyembryony is found well distributed through the Spermatophytes though occurring more frequently in the Gymnosperms than in the Angiosperms. The additional embryo or embryos, which may be either sporophytic or gametophytic in origin, may arise in a variety of ways. Ernst[1] in 1901 pointed out that the cells of the (1) nucellus, (2) integuments, (3) a second egg, (4) a synergid, (5) fragmentation of the normal embryo, (6) the antipodals, (7) the endosperm, (8) or the suspensor may be responsible for the phenomenon.

The occurrence of polyembryony in the Angiosperms is summarized in the following table which is compiled from Ernst[1] and Coulter and Chamberlain[2]. The distribution is shown according to the Alliances, in which I have followed the scheme of Engler and Gilg.[3]

OCCURRENCE OF POLYEMBRYONY IN ANGIOSPERMS.

A—Archichlamydeae

| | |
|---|---|
| XI. Fagales | Quercus alba. |
| XIV. Santalales | Balanopora elongata. |
| | Balanopora globosa. |
| | Helosis guayanensis. |
| | Loranthus europaeus (?). |
| | Santalum album. |
| XVIII. Ranales | Aconitum Napellus. |
| XIX. Rhoeadales | Glaucium luteum. |
| XXI. Rosales | Mimosa Denhartii. |
| | Schrankia uncinata. |
| XXIII. Gerinales | Citrus aurantium. |
| | Euphorbia dulcis. |
| XXIV. Sapindales | Euonymus latifolius. |
| | Euonymus americanus. |
| | Mangifera indica. |
| XXVII. Parietales | Clusia alba. |
| XXVIII. Opuntiales | Opuntia vulgaris. |
| | Opuntia tortispina. |

B—Sympetalae

| | |
|---|---|
| V. Gentianales | Vincetoxicum nigrum. |
| | Vincetoxicum medium. |
| VI. Tubiflorales | Sinningia Lindleyana. |
| VIII. Campanales | Alchemilla pastoralis. |
| | Alchemilla sericata. |
| | Taraxacum officinalis. |

C—Monocotyledonae

| | |
|---|---|
| I. Panadanales | Limnocharis emarginata. |
| | Naias major. |
| IX. Lilliales | Allium odorum. |
| | Erythronium americanum. |
| | Erythronium dens-canis. |
| | Funkia ovata. |
| | Iris sibirica. |
| | Lillium martagon. |
| | Nothoscordon fragrans. |
| | Tulipa Gesneriana. |
| XI. Orchidales | Coelo(bo)gyne ilicifolia. |
| | Gymndenia conopsea. |

Dr. Coulter in a recent letter states: "I know of no record of polyembryony in the Archichlamydeae since the date of the Angiosperm volume." It would thus seem probable that these thirty-six cases scattered through fifteen of the forty-nine Alliances gives a fair representation of our knowledge of the occurrence of polyembryony in the Angiosperms. It is to be noted, however, that, in the words of Coulter[2] "the cases on record are already so numerous that only an exhaustive study of the literature would make it safe to venture an estimate of the number. Since in nearly all the cases described this phenomenon is rare rather than habitual, it is probable that under conditions not yet understood a large number of plants may exhibit polyembryony occasionally."

This new case of polyembryony came to my notice in a collection of germinating acorns brought into the laboratory for class use in the spring of 1916. Among them one acorn was discovered possessing two well formed and vigorous embryos as can readily be seen from the specimen submitted. The embryos are so far advanced that it is impossible to determine their origin except that it is certain that they lay within the same nucellus. Careful search in the field failed to reveal any additional cases.

Polyembryony in *Quercus alba* is of especial interest as it is the first case to be discovered in the first thirteen Alliances of the Archichlamydeae.

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## INTRA-MICROSPORANGIAL DEVELOPMENT OF THE TUBE IN THE MICROSPORE OF *PINUS SYLVESTRIS.*

BY LE ROY H. HARVEY.

The staminate inflorescences were collected in large quantities May 2, 1910, from a tree well exposed and from 60 to 70 years of age. The material was obtained for class work in General Morphology. The cones measured from five to seven mm. long and pollination probably took place within the next ten days though no record was made. From one to two per cent of the microspores in all the material examined showed pollen-tube development, the tube ranging in length from just-rupturing-the-exine to .092 mm. In several cases two tubes were observed arising at opposite poles of the microspore.

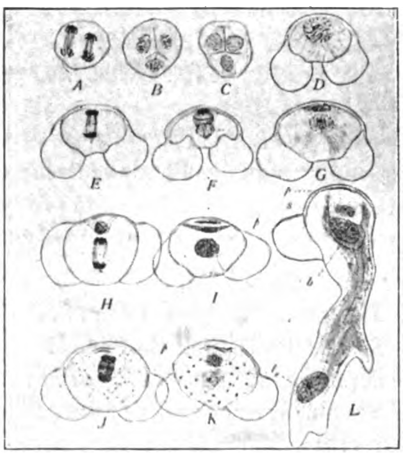


Figure 16. Pinus laricio (after Coulter and Chamberlain).

To bring to your attention the normal course of development of the microspore I quote from Coulter and Chamberlain.[1] "About May 9 (in Chicago) the nucleus of the microspore of Pinus Laricio enlarges for the first division (Fig. 16-D), a spindle is formed rapidly (Fig. 16-E) and an equal division follows. Before the cell plate is organized, the nucleus nearer to the wall of the spore begins to disorganize, and the other begins to enlarge (Fig. 16-F). In this way a lenticular and disorganizing cell is cut off against the spore wall (Fig. 16-G). A second

division follows immediately, a spindle being observed about May 25, (Fig. 16-H). This division is a repetition of the first in details and the two lenticular cells disorganize rapidly, (Fig. 16-I), become flattened against the spore wall, and very soon appear merely as two thin and deeply staining disks, which are overgrown rapidly by the intine. * * * *

"The third (large) cell, which is a sister to the second evanescent vegetative cell, is an antheridial cell in the sense that it gives rise to a series of cells which represent the antheridium in function, but not at all in structure. The division of this cell follows immediately giving rise to the generative and tube cell * * * *

"No further division takes place until the following spring, a period of about eleven months, and in this condition pollination occurs. * * * * The pollen tube begins to grow into the nucellus as soon as the spore is deposited, and continues to develop until it is checked by cold weather. The next spring (third spring) the tube begins to renew its penetration of the nucellus during April, about a year after the pollen mother cell entered upon the reduction divisions, the large tube nucleus enters the tube and at the same time the generative cell divides into the stalk cell and body cell (Fig. 16-L). * * * * After its second start the pollen tube consumes about two months in traversing the nucellus, reaching the archegonium about the first of July."

An epitome of this data may be presented with the aid of Fig. 16, which is taken from Coulter and Chamberlain.[1]

### SUMMARIZATION OF MICROSPORE DEVELOPMENT.

About May 1-10—Tetrad Division Mother Spore Cell....Fig. 16-A-C
About May 10-20—Formation of First Prothallial Cell...Fig. 16-D-G
About May 20-25—Second Prothallial Cell cut off........Fig. 16-H-J
About June 15—Generative and Tube Cell Formed.......Fig. 16-K
June 15-May 15 of Second Spring—No Change..........Fig. 16-K
About May 15—*Pollination* ..........................Fig. 16-K
May 15—Fall—Penetration of Pollen Tube.............Fig. 16-L
About May 1 of Third Spring—Resumption of Growth....Fig. 16-L
About July 1 of Third Spring—Fertilization.

While this data is for *P. Laricio* it will no doubt stand approximately for the normal condition in *P. sylvestris*. Fig. 16-K which represents the condition of the microspore at the time of pollination is of especial interest. In our material (Fig. 17) this condition of the microspore showing generative and tube cell was abundantly seen (Fig. 17-3 and 4), indicating a normal development as far as nuclear condition is concerned. The anomalous condition of our material is shown by Fig. 17-

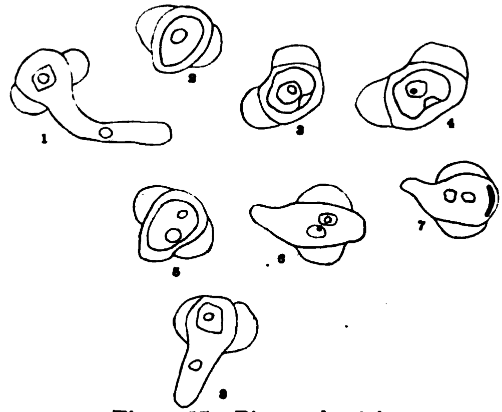


Figure 17. Pinus sylvestris.

5, 7, 8, 1. Various stages of pollen tube elongation are here illustrated as well as one case with two tubes (Fig. 17-6). All seem to show the generative and tube cell stage. No evidence of a division of the generative cell into the stalk cell and body cell was found, though the tube compares almost exactly in length to that shown in Fig. 16-L from Coulter and Chamberlain and the tube nucleus is in the expected position for this stage. It is to be noted that Coulter and Chamberlain's figure (Fig. 16-L) records the condition after four or five months' development within the nucellus of the ovule. The position of the tube nucellus, however, is responsible for the tube elongation and is not to be considered as evidence of the nuclear condition in the spore.

It has been assumed that tube development was a chemotropic response; the stimulus arising from a mucilagenous substance secreted by the nucellus—the so-called "pollination-drop"—or from contact with the nucellus. Just what our observation may mean is problematical. That the primitive function of the pollen tube in the Gymnosperms was haustorial and that its present function in Siphonogamy derived is, I believe, generally acknowledged. Whether this anomalous development of the pollen tube within the microsporangium is to be interpreted as recapitulative or as a response to some unusual intra-microsporangial nutritive condition can only be answered by further investigation. In any case it is evident that the chemotropic stimulus of the nucellus or pollination-drop is not essential for the development of the pollen tube in *Pinus sylvestris*.

## LITERATURE CITED.

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# THE EFFECT UPON THE GROWTH OF SOME CONIFEROUS SEEDLINGS OF VARIOUS CONDITIONS OF SHADE AND MOISTURE.*

BY PAUL C. KITCHIN.

It has long been the practice, and still is in many places, to consider the shading of coniferous seedlings, at least until the end of the first year, as essential to their proper development. According to Toumey, experiments in many locations have proved that this shading is not essential, though the advantage or disadvantage of shading should be proved for any specific locality before it is dispensed with. To prove, then, the economic advantage, or disadvantage, of shading for the Forest Nursery, located at the Michigan Agricultural College, is the object of the work herein detailed. It was carried on under the supervision of Prof. A. K. Chittenden of the M. A. C. Forestry Department.

The experiment was run in three parts, using different seedlings in each part. Up to the time when the work was started, all four sections of each group had developed under similar conditions, hence the comparisons and contrasts on any one set should show the approximate truth. The three species used were (1) Pinus strobus, (2) Pinus resinosa and (3) Picea excelsa. With the exception of the fact that maximum and minimum temperatures were determined for the air just above each of the four parts of the Pinus strobus bed, all the species had identical treatment as follows:

The seedling bed (about twenty linear feet of ordinary four feet wide seed bed) was divided into four equal parts of five linear feet each and these parts will subsequently be known as I, II, III and IV respectively. Bed I was given full shade by means of a burlap cover, and received no water, except that rainfall which filtered through (see precipitation reports appended). Bed II was given one-half shade by means of the ordinary lath covering, and no water except as noted for I. Bed III was treated as a check, receiving no shade and no water, excepting rainfall. Bed IV was given no shade and watered well every evening, besides the rainfall it received. (Plate XVII.) In the case of the Pinus strobus, the maximum and minimum temperatures for each part for each 24 hours were noted and tabulated. The fact that the temperatures of the air,

*Submitted for credit (in part) leading to the degree of Master of Science from the Michigan Agricultural College.

so taken, are not soil temperatures, and have not the effect on growth that the latter may have, is appreciated; they are given that a general conception of heat and cold conditions, under which the work took place, may be more fully understood. Other weather reports are taken directly from the records of the U. S. Weather Bureau of East Lansing. (Appendix, Tables I, II, III, IV.) It will be noted that the season was an ideal one for such an experiment, due to the long continued dry weather of July and August, and this must be borne in mind when comparing the growth of root systems of parts II, III and IV of each section of the experiment.

Before starting the experiment, all of the seed beds used had previously been attacked by a damping off fungus, and in the case of Pinus resinosa the number of seedlings so depleted that full data could not be secured on beds I, II and III at the end of the experiment. For this reason the photograph of bunches of 50 seedlings from each bed of P. resinosa were not available, though a photograph of two seedlings from each section was made.

The photographs included in this report were made by Mr. W. I. Gilson of the Forestry Department. The groups of seedlings photographed number 50 in every case, unless otherwise designated, and the conditions under which they were grown is shown in the photograph. The graphs were plotted from the data collected and given here in tabulated form.

## PINUS STROBUS.

The seeds of Pinus strobus were planted in the fall of 1915 (Nov. 19). The first measurements, taken after the beginning of the experiment, (June 28, 1916) were made at that time, and show practically the same figures for all four parts of the experiment. On account of the scarcity of the plants, due to their having damped off earlier in the season, only a few were dug and measurements made of two representative plants. These figures are given below:

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 3.0 cm. | 3.5 cm. |
| 2.0 | 3.0 | 3.5 |
| 3.5 | 6.0 | 7.0 |
| Av. 1.7 | Av. 3.0 | Av. 3.5 |

On July 5, 1916, measurements were made of two representative plants from each of the four parts of the experiment and are given below under the headings I, II, III and IV, which have been explained previously.

### No. I.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 cm. | 4.0 cm. | 3.0 cm. |
| 1.5 | 3.0 | 4.0 |
| 3.5 | 7.0 | 7.0 |
| Av. 1.7 | Av. 3.5 | Av. 3.5 |

### No. III.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 3.0 cm. | 3.0 cm. |
| 2.0 | 3.0 | 2.5 |
| 3.5 | 6.0 | 5.5 |
| Av. 1.7 | Av. 3.0 | Ay. 2.7 |

### No. II.

| | | |
|---|---|---|
| 2.0 | 3.0 | 2.5 |
| 2.0 | 3.0 | 2.0 |
| 4.0 | 6.0 | 4.5 |
| Av. 2.0 | Av. 3.0 | Av. 2.2 |

### No. IV.

| | | |
|---|---|---|
| 1.5 | 3.0 | 2.0 |
| 1.0 | 2.5 | 3.0 |
| 2.5 | 5.5 | 5.0 |
| Av. 1.3 | Av. 2.7 | Av. 2.5 |

The next set of measurements was made July 12, 1916, and was as follows:

### No. I.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 3.5 cm. | 2.0 cm. |
| 1.5 | 3.0 | 3.5 |
| 3.0 | 6.5 | 5.5 |
| Av. 1.5 | Av. 3.2 | Av. 2.7 |

### No. III.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 4.5 cm. | 3.5 cm. |
| 1.5 | 5.0 | 5.5 |
| 3.0 | 9.5 | 9.0 |
| Av. 1.5 | Av. 4.7 | Av. 4.5 |

### No. II.

| | | |
|---|---|---|
| 1.5 | 4.5 | 2.0 |
| 1.5 | 4.0 | 6.0 |
| 3.0 | 8.5 | 8.0 |
| Av. 1.5 | Av. 4.3 | Av. 4.0 |

### No. IV.

| | | |
|---|---|---|
| 1.5 | 4.0 | 3.5 |
| 1.5 | 4.0 | 6.5 |
| 3.0 | 8.0 | 10.0 |
| Av. 1.5 | Av. 4.0 | Av. 5.0 |

The measurements taken August 9, 1916, were as follows:

### No. I.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.5 cm. | 3.3 cm. | 11.0 cm. |
| 1.5 | 3.0 | 6.5 |
| 4.0 | 6.3 | 17.5 |
| Av. 2.0 | Av. 3.2 | Av. 8.7 |

### No. III.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 3.0 cm. | 4.3 cm. | 12.0 cm. |
| 2.5 | 3.5 | 10.0 |
| 2.2 | 3.3 | 11.5 |
| 1.0 | 2.7 | 7.5 |
| 2.5 | 3.8 | 8.2 |
| 2.3 | 3.0 | 8.0 |
| 2.5 | 3.0 | 10.5 |
| 2.5 | 3.7 | 11.5 |
| 18.5 | 27.3 | 79.2 |
| Av. 2.3 | Av. 3.4 | Av. 9.9 |

### No. II.

| | | |
|---|---|---|
| 2.0 | 3.5 | 4.5 |
| 2.5 | 2.5 | 8.0 |
| 3.0 | 2.5 | 9.5 |
| 2.5 | 4.0 | 9.0 |
| 2.0 | 3.0 | 8.0 |
| 2.2 | 3.5 | 10.0 |
| 2.5 | 4.0 | 5.5 |
| 16.7 | 23.0 | 54.5 |
| Av. 2.4 | Av. 3.3 | Av. 7.7 |

### No. IV.

| | | | |
|---|---|---|---|
| 3.5 | 2.5 | 7.0 | |
| 3.0 | 3.5 | 16.0 | |
| 3.0 | 3.3 | 6.5 | (13.0 lateral) |
| 3.5 | 2.5 | 11.0 | |
| 2.5 | 3.3 | 8.0 | |
| 3.0 | 1.5 | 10.0 | |
| 18.5 | 16.6 | 58.5 | |
| Av. 3.1 | Av. 2.8 | Av. 9.8 | |

The following measurements were taken at the completion of the work, September 26, 1916.

PINUS STROBUS NO. I.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 cm. | 3.0 cm. | 7.5 cm. |
| 2.0 | 3.5 | 9.5 |
| 2.5 | 3.0 | 6.0 |
| 1.5 | 3.5 | 2.5 |
| 1.5 | 3.0 | 8.5 |
| 2.0 | 4.5 | 8.5 |
| 2.0 | 3.0 | 10.5 |
| 2.0 | 3.0 | 6.5 |
| 2.5 | 4.0 | 7.0 |
| 2.5 | 4.0 | 6.0 |
| 2.0 | 5.5 | 8.5 |
| 1.5 | 5.5 | 6.0 |
| 2.0 | 3.5 | 7.0 |
| 1.5 | 3.5 | 3.5 |
| 2.0 | 3.5 | 8.0 |
| 2.5 | 4.0 | 7.5 |
| 2.5 | 3.5 | 7.0 |
| 1.5 | 4.0 | 7.0 |
| 2.0 | 4.5 | 6.0 |
| 2.0 | 4.0 | 9.5 |
| 2.0 | 4.0 | 9.0 |
| 2.0 | 3.0 | 8.0 |
| 2.0 | 4.0 | 5.5 |
| 2.0 | 4.0 | 4.5 |
| 2.5 | 3.5 | 8.5 |
| 2.0 | 3.5 | 7.5 |
| 2.0 | 4.0 | 7.0 |
| 1.5 | 3.5 | 2.5 |
| 1.5 | 4.5 | 5.5 |
| 1.5 | 3.5 | 5.0 |
| 2.0 | 3.0 | 11.0 |
| 2.0 | 4.0 | 8.0 |
| 1.5 | 3.0 | 3.5 |
| 1.5 | 3.0 | 4.5 |
| 2.0 | 4.0 | 6.0 |
| 1.5 | 4.5 | 6.0 |
| 2.0 | 4.0 | 8.5 |
| 2.0 | 3.0 | 6.0 |
| 1.5 | 5.0 | 10.0 |
| 2.0 | 4.5 | 11.0 |
| 2.0 | 3.5 | 6.5 |
| 1.5 | 4.0 | 7.0 |
| 1.5 | 4.5 | 6.5 |
| 1.5 | 3.5 | 6.5 |
| 1.5 | 3.0 | 5.5 |
| 1.5 | 2.5 | 4.0 |
| 2.0 | 3.0 | 2.5 |
| 2.0 | 3.5 | 6.0 |
| 2.0 | 4.0 | 7.0 |
| 1.5 | 5.0 | 9.5 |
| 94.0 | 189.5 | 341.0 |
| Av. 1.9 | Av. 3.8 | Av. 6.8 |

PINUS STROBUS NO. II.

| Top. | Hypocotyl. | Tap Root. | |
|---|---|---|---|
| 3.0 cm. | 4.0 cm. | 15.0 cm. | |
| 4.0 | 5.0 | 15.5 | |
| 2.5 | 4.0 | 11.0 | |
| 2.5 | 4.0 | 11.5 | |
| 2.5 | 3.5 | 6.0 | |
| 1.5 | 4.0 | 5.0 | |
| 2.0 | 4.0 | 7.5 | |
| 2.5 | 5.0 | 6.5 | |
| 3.5 | 5.0 | 15.0 | |
| 3.0 | 5.0 | 10.0 | |
| 3.0 | 4.5 | 16.0 | |
| 2.0 | 4.0 | 7.5 | |
| 2.5 | 4.0 | 7.0 | |
| 3.0 | 3.5 | 9.0 | |
| 3.0 | 5.5 | 13.0 | |
| 2.5 | 5.0 | 5.5 | |
| 3.0 | 5.0 | 6.0 | |
| 2.5 | 4.5 | 8.0 | |
| 3.0 | 5.0 | 6.0 | |
| 3.0 | 4.0 | 8.5 | |
| 4.0 | 5.0 | 11.5 | |
| 2.5 | 4.0 | 14.5 | |
| 3.0 | 4.5 | 6.5 | |
| 2.0 | 4.0 | 7.0 | |
| 3.5 | 4.5 | 10.0 | |
| 3.5 | 4.0 | 8.0 | |
| 4.0 | 4.0 | 17.0 | |
| 4.0 | 4.0 | 14.0 | |
| 3.5 | 3.5 | 17.0 | |
| 3.0 | 4.5 | 18.0 | |
| 4.0 | 5.0 | 7.5 | |
| 3.0 | 4.0 | 13.0 | |
| 3.0 | 5.0 | 15.5 | |
| 2.5 | 4.0 | 5.0 | |
| 2.5 | 5.0 | 11.5 | |
| 2.0 | 4.5 | 13.0 | |
| 3.0 | 5.5 | 8.0 | |
| 3.5 | 4.5 | 8.5 | |
| 2.5 | 4.0 | 11.0 | |
| 2.5 | 5.0 | 11.5 | |
| 3.5 | 5.0 | 9.5 | (12.0 lateral) |
| 4.0 | 4.0 | 9.0 | |
| 4.0 | 5.0 | 11.0 | |
| 3.0 | 4.5 | 9.5 | |
| 4.0 | 4.0 | 21.0 | |
| 3.0 | 3.5 | 14.5 | |
| 3.0 | 4.0 | 5.0 | |
| 2.5 | 4.5 | 13.5 | |
| 2.0 | 4.5 | 7.0 | |
| 2.0 | 4.5 | 4.0 | |
| 147.0 | 220.5 | 521.5 | |
| Av. 2.9 | Av. 4.4 | Av. 10.4 | |

**PINUS STROBUS NO. III.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 3.5 cm. | 3.5 cm. | 6.5 cm. |
| 3.0 | 4.5 | 18.5 |
| 3.0 | 4.5 | 13.5 |
| 3.0 | 4.5 | 15.5 |
| 3.0 | 4.0 | 13.5 |
| 2.5 | 4.0 | 11.0 |
| 3.0 | 3.5 | 8.0 |
| 2.5 | 3.0 | 14.0 |
| 2.5 | 4.0 | 14.0 |
| 2.5 | 4.0 | 9.5 |
| 3.0 | 3.5 | 8.5 |
| 3.0 | 4.0 | 7.0 |
| 3.0 | 4.0 | 16.0 |
| 1.5 | 4.0 | 10.5 |
| 2.5 | 4.0 | 6.0 |
| 2.0 | 4.0 | 8.0 |
| 2.5 | 3.0 | 19.0 |
| 2.5 | 3.5 | 8.5 |
| 3.5 | 3.5 | 14.5 |
| 2.5 | 3.5 | 8.0 |
| 2.5 | 4.0 | 12.0 |
| 2.0 | 3.0 | 6.5 |
| 2.5 | 3.0 | 14.0 |
| 2.5 | 3.0 | 8.0 |
| 2.5 | 3.5 | 12.0 |
| 3.0 | 4.5 | 16.0 |
| 2.5 | 3.0 | 17.0 |
| 3.0 | 3.5 | 11.5 |
| 3.0 | 3.0 | 16.5 |
| 2.0 | 3.5 | 8.0 |
| 3.0 | 3.5 | 16.0 |
| 4.0 | 3.0 | 22.0 |
| 2.5 | 3.0 | 10.5 |
| 3.5 | 3.0 | 19.0 |
| 3.0 | 3.0 | 16.5 |
| 2.5 | 3.5 | 10.0 |
| 2.5 | 3.0 | 17.0 |
| 2.5 | 4.0 | 13.0 |
| 3.5 | 3.5 | 18.0 |
| 3.5 | 4.5 | 20.0 |
| 3.5 | 4.0 | 13.0 |
| 3.0 | 4.0 | 11.0 |
| 3.5 | 4.5 | 14.5 |
| 3.0 | 4.0 | 10.0 |
| 3.5 | 3.5 | 14.5 |
| 3.0 | 3.5 | 17.0 |
| 3.0 | 4.0 | 16.5 |
| 4.0 | 3.5 | 18.0 |
| 3.0 | 3.5 | 12.5 |
| 3.0 | 4.0 | 13.0 |
| 148.0 | 188.0 | 653.5 |
| Av. 2.9 | Av. 3.7 | Av. 13.1 |

**PINUS STROBUS NO. IV.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.5 cm. | 4.5 cm. | 14.0 cm. |
| 2.5 | 3.5 | 4.0 (6.5 lateral) |
| 4.0 | 3.5 | 16.0 |
| 3.5 | 3.5 | 14.0 |
| 2.5 | 3.5 | 8.0 (7.0 lateral) |
| 3.0 | 4.5 | 9.0 |
| 4.5 | 3.5 | 14.5 |
| 2.5 | 3.5 | 15.5 |
| 4.0 | 4.5 | 10.0 |
| 3.5 | 2.5 | 14.0 |
| 2.5 | 3.5 | 14.0 |
| 3.0 | 4.5 | 9.5 |
| 2.5 | 3.5 | 18.0 |
| 4.5 | 4.0 | 16.5 |
| 2.5 | 3.5 | 8.5 |
| 4.5 | 4.0 | 21.0 |
| 3.5 | 4.0 | 18.0 |
| 4.0 | 4.0 | 16.0 |
| 4.5 | 5.0 | 18.0 |
| 4.5 | 3.5 | 15.0 |
| 3.5 | 4.5 | 18.0 |
| 2.5 | 4.5 | 11.0 |
| 3.5 | 4.5 | 20.0 |
| 2.5 | 4.0 | 6.0 |
| 3.0 | 4.0 | 13.0 |
| 4.0 | 3.0 | 11.0 |
| 4.0 | 4.0 | 15.0 |
| 4.0 | 3.5 | 18.0 |
| 3.5 | 4.5 | 14.5 |
| 3.0 | 4.0 | 15.0 |
| 2.5 | 3.0 | 13.0 |
| 3.5 | 4.0 | 15.0 |
| 4.0 | 4.0 | 13.0 |
| 3.5 | 4.5 | 13.0 |
| 2.0 | 4.0 | 11.0 |
| 4.0 | 4.0 | 11.5 |
| 3.0 | 3.0 | 9.5 |
| 3.0 | 3.5 | 19.0 |
| 2.5 | 3.0 | 16.0 |
| 4.0 | 4.0 | 12.0 |
| 3.5 | 3.0 | 13.5 |
| 4.0 | 3.5 | 13.0 |
| 3.5 | 5.0 | 12.5 |
| 3.5 | 4.0 | 11.5 |
| 3.0 | 3.5 | 15.0 |
| 3.0 | 3.5 | 8.0 |
| 3.5 | 5.0 | 15.0 |
| 3.0 | 4.0 | 16.0 |
| 3.0 | 3.5 | 12.0 |
| 3.5 | 4.5 | 16.0 |
| 167.5 | 193.5 | 680.5 |
| Av. 3.3 | Av. 3.9 | Av. 13.6 |

The average tap root curve would lead to the expectation, within a reasonable range, of the following tap root lengths, in Pinus strobus at 10-day intervals during the major part of a normal growing season in the M. A. C. Forest Nursery.

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| June 28 .................. | 3.5 cm. | 3.5 cm. | 3.5 cm. | 3.5 cm. |
| July 8 .................. | 3.8 | 4.3 | 4.5 | 4.6 |
| July 18 .................. | 4.2 | 5.0 | 5.6 | 5.7 |
| July 28 .................. | 4.6 | 5.8 | 6.7 | 6.8 |
| August 7 .................. | 4.9 | 6.5 | 7.7 | 8.0 |
| August 17 .................. | 5.3 | 7.3 | 8.8 | 9.1 |
| August 27 .................. | 5.7 | 8.1 | 9.8 | 10.2 |
| September 6 .............. | 6.0 | 8.9 | 11.0 | 11.4 |
| September 16 .............. | 6.4 | 9.6 | 12.0 | 12.5 |
| September 26 .............. | 6.8 | 10.4 | 13.1 | 13.6 |

### PICEA EXCELSA.

The Picea excelsa seeds were sown in the spring of 1916 (April 26) and the beds were reasonably well filled when the experiment was started. The damping off seemed to have affected this bed less than the other two.

The results of the preliminary measurements made at the start (June 28, 1916) were as follows:

**Nos. I, II, III, IV.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.0 cm. | 1.5 cm. | 1.5 cm. |
| 1.0 | 1.0 | 1.5 |
| 2.0 | 2.5 | 3.0 |
| Av. 1.0 | Av. 1.2 | Av. 1.5 |

Measurements of July 5, 1916, were:

**No. I.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 1.5 cm. | 4.0 cm. |
| 1.5 | 1.5 | 3.7 |
| 3.0 | 3.0 | 7.7 |
| Av. 1.5 | Av. 1.5 | Av. 3.8 |

**No. III.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 1.5 cm. | 2.7 cm. |
| 2.0 | 1.3 | 2.0 |
| 3.5 | 2.8 | 4.7 |
| Av. 1.7 | Av. 1.4 | Av. 2.3 |

**No. II.**

| | | |
|---|---|---|
| 1.5 | 1.0 | 3.5 |
| 1.7 | 1.0 | 3.5 |
| 3.2 | 2.0 | 7.0 |
| Av. 1.6 | Av. 1.0 | Av. 3.5 |

**No. IV.**

| | | |
|---|---|---|
| 1.0 | 1.0 | 3.5 |
| 1.0 | 1.0 | 2.5 |
| 2.0 | 2.0 | 6.0 |
| Av. 1.0 | Av. 1.0 | Av. 3.0 |

Measurements of July 12, 1916, were:

**No. I.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 1.0 cm. | 3.5 cm. |
| 1.5 | 1.5 | 5.5 |
| 3.0 | 2.5 | 9.0 |
| Av. 1.5 | Av. 1.2 | Av. 4.5 |

**No. III.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 cm. | 1.0 cm. | 4.5 cm. |
| 1.0 | 1.0 | 3.0 |
| 1.5 | 1.0 | 3.5 |
| 4.5 | 3.0 | 11.0 |
| Av. 1.5 | Av. 1.0 | Av. 3.7 |

**No. II.**

| | | |
|---|---|---|
| 1.5 | 1.0 | 3.5 |
| 2.0 | 1.5 | 3.5 |
| 3.5 | 2.5 | 7.0 |
| Av. 1.7 | Av. 1.2 | Av. 3.5 |

**No. IV.**

| | | |
|---|---|---|
| 1.5 | 1.0 | 2.5 |
| 1.5 | 1.5 | 5.0 |
| 3.0 | 2.5 | 7.5 |
| Av. 1.5 | Av. 1.2 | Av. 3.7 |

**Measurements taken August 9, 1916, were:**

### No. I.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.7 cm. | 2.0 cm. | 4.5 cm. |
| 1.5 | 1.7 | 4.0 |
| 1.0 | 2.0 | 6.0 |
| 1.5 | 1.2 | 3.0 |
| 2.0 | 1.5 | 8.0 |
| 1.5 | 1.3 | 4.5 |
| 9.2 | 9.7 | 30.0 |
| Av. 1.5 | Av. 1.6 | Av. 5.0 |

### No. II.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.5 cm. | 2.0 cm. | 6.0 cm. |
| 2.0 | 2.0 | 10.5 |
| 3.0 | 1.5 | 5.5 |
| 1.7 | 2.0 | 6.0 |
| 2.0 | 2.0 | 11.0 |
| 3.0 | 1.7 | 17.0 |
| 2.7 | 1.7 | 17.0 |
| 2.0 | 2.0 | 8.0 |
| 2.0 | 1.7 | 7.0 |
| 2.2 | 2.3 | 7.5 |
| 3.0 | 2.0 | 13.0 |
| 2.0 | 1.5 | 9.0 |
| 1.9 | 1.5 | 9.5 |
| 2.5 | 1.5 | 9.5 |
| 2.0 | 1.5 | 6.5 |
| 2.5 | 1.7 | 11.5 |
| 37.0 | 28.6 | 154.5 |
| Av. 2.3 | Av. 1.7 | Av. 9.7 |

### No. III.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 cm. | 2.0 cm. | 7.0 cm. |
| 2.5 | 1.3 | 9.5 |
| 2.0 | 1.5 | 8.5 |
| 1.5 | 1.5 | 5.5 |
| 2.0 | 2.0 | 9.5 |
| 2.0 | 1.7 | 6.0 |
| 2.5 | 1.0 | 9.0 |
| 1.5 | 1.5 | 5.5 |
| 1.5 | 1.3 | 12.0 |
| 2.3 | 1.3 | 11.0 |
| 3.0 | 1.5 | 10.0 |
| 3.0 | 2.0 | 12.0 |
| 2.0 | 1.3 | 9.0 |
| 27.8 | 19.9 | 114.5 |
| Av. 2.1 | Av. 1.6 | Av. 8.8 |

### No. IV.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 cm. | 1.7 cm. | 5.5 cm. |
| 1.5 | 2.0 | 7.5 |
| 1.5 | 2.5 | 13.0 |
| 3.0 | 1.5 | 12.0 |
| 3.0 | 2.0 | 9.0 |
| 1.5 | 1.7 | 12.0 |
| 2.5 | 1.7 | 12.5 |
| 2.0 | 1.5 | 10.0 |
| 2.5 | 1.5 | 11.0 |
| 2.5 | 1.5 | 11.0 |
| 2.0 | 2.0 | 11.5 |
| 1.5 | 1.7 | 9.0 |
| 25.5 | 21.3 | 124.0 |
| Av. 2.1 | Av. 1.8 | Av. 10.3 |

## Measurements taken September 26, 1916:

| PICEA EXCELSA NO. I. | | | PICEA EXCELSA NO. II. | | |
|---|---|---|---|---|---|
| Top. | Hypocotyl. | Tap Root. | Top. | Hypocotyl. | Tap Root. |
| 1.5 cm. | 1.5 cm. | 5.0 cm. | 4.5 cm. | 2.5 cm. | 11.5 cm. |
| 1.5 | 1.5 | 5.0 | 4.5 | 2.0 | 12.0 |
| 1.5 | 1.5 | 4.0 | 4.5 | 2.5 | 8.0 |
| 1.0 | 1.5 | 3.5 | 5.0 | 2.5 | 11.5 |
| 1.5 | 1.5 | 4.5 | 3.5 | 2.0 | 8.5 |
| 1.0 | 2.0 | 3.0 | 4.0 | 2.0 | 9.0 |
| 1.5 | 2.0 | 4.0 | 3.0 | 2.0 | 15.0 |
| 2.0 | 1.5 | 4.0 | 2.5 | 2.0 | 12.0 |
| 2.0 | 2.5 | 6.0 | 2.0 | 2.0 | 7.5 |
| 2.0 | 2.0 | 4.0 | 3.0 | 1.0 | 11.0 |
| 1.5 | 2.0 | 6.0 | 2.0 | 1.5 | 10.5 |
| 1.5 | 2.0 | 4.5 | 4.5 | 2.0 | 14.0 |
| 2.0 | 2.0 | 5.0 | 3.0 | 2.0 | 14.5 |
| 2.0 | 1.5 | 6.5 | 4.0 | 2.5 | 9.0 |
| 2.0 | 2.0 | 5.5 | 2.0 | 2.0 | 9.5 |
| 1.0 | 1.5 | 3.0 | 3.5 | 1.0 | 13.5 |
| 1.5 | 2.0 | 3.5 | 4.5 | 2.0 | 10.0 |
| 1.5 | 2.0 | 4.0 | 2.0 | 2.0 | 9.5 |
| 1.5 | 2.0 | 4.5 | 2.5 | 2.0 | 12.0 |
| 1.0 | 1.5 | 5.0 | 4.0 | 1.5 | 7.0 |
| 1.5 | 1.5 | 4.5 | 2.5 | 2.0 | 9.0 |
| 1.5 | 2.0 | 8.5 | 3.0 | 2.0 | 15.0 |
| 1.0 | 1.5 | 4.0 | 5.5 | 3.0 | 13.0 |
| 1.5 | 2.0 | 3.5 | 3.5 | 2.5 | 11.5 |
| 2.0 | 2.5 | 3.5 | 5.0 | 1.5 | 13.0 |
| 1.5 | 1.5 | 4.5 | 3.0 | 1.5 | 13.0 |
| 1.5 | 2.0 | 5.0 | 4.0 | 2.0 | 14.0 |
| 1.5 | 2.0 | 3.0 | 3.0 | 2.0 | 10.5 |
| 1.5 | 2.0 | 4.5 | 4.0 | 2.0 | 13.0 |
| 1.5 | 2.0 | 3.0 | 4.0 | 2.0 | 13.0 |
| 1.5 | 2.0 | 3.5 | 6.0 | 2.0 | 9.0 |
| 1.5 | 2.0 | 8.0 | 2.0 | 2.0 | 14.5 |
| 1.0 | 2.0 | 4.0 | 3.5 | 2.5 | 16.0 |
| 1.5 | 1.5 | 4.5 | 3.0 | 2.0 | 17.0 |
| 1.5 | 1.5 | 6.5 | 3.0 | 1.5 | 10.0 |
| 1.5 | 1.0 | 4.0 | 3.5 | 2.0 | 15.0 |
| 1.5 | 2.0 | 7.5 | 2.0 | 2.0 | 12.0 |
| 1.5 | 1.5 | 5.5 | 4.5 | 2.5 | 11.0 |
| 1.5 | 1.5 | 4.0 | 2.5 | 2.0 | 5.0 |
| 1.5 | 1.5 | 7.0 | 3.0 | 2.0 | 12.0 |
| 1.5 | 1.5 | 5.5 | 3.5 | 2.0 | 7.0 |
| 1.5 | 1.5 | 4.5 | 3.5 | 2.0 | 23.0 |
| 1.5 | 1.5 | 4.0 | 3.5 | 2.0 | 13.5 |
| 1.5 | 1.5 | 3.5 | 2.5 | 1.5 | 10.5 |
| 1.0 | 1.5 | 5.0 | 3.0 | 2.0 | 10.5 |
| 1.5 | 2.0 | 5.5 | 3.0 | 2.5 | 7.5 |
| 1.5 | 1.5 | 4.5 | 5.0 | 2.0 | 14.0 |
| 2.0 | 2.0 | 8.0 | 2.0 | 2.0 | 12.5 |
| 1.0 | 1.5 | 2.5 | 2.5 | 2.0 | 6.0 |
| 2.0 | 2.0 | 8.0 | 3.5 | 2.0 | 13.0 |
| 65.5 | 88.0 | 240.0 | 171.0 | 100.0 | 579.5 |
| Av. 1.3 | Av. 1.8 | Av. 4.8 | Av. 3.4 | Av. 2.0 | Av. 11.6 |

**PICEA EXCELSA NO. III.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 4.0 cm. | 2.0 cm. | 17.0 cm. |
| 3.5 | 2.0 | 20.0 |
| 2.0 | 2.0 | 12.0 |
| 2.5 | 1.5 | 15.0 |
| 3.0 | 2.0 | 18.0 |
| 1.0 | 1.5 | 11.0 |
| 2.5 | 1.5 | 9.0 |
| 3.0 | 1.5 | 15.5 |
| 4.0 | 2.0 | 20.0 |
| 3.0 | 1.5 | 24.0 |
| 3.0 | 1.5 | 18.5 |
| 3.5 | 1.5 | 10.0 |
| 1.5 | 2.0 | 9.0 |
| 2.5 | 1.5 | 11.0 |
| 2.0 | 2.0 | 9.0 |
| 2.0 | 1.5 | 9.5 |
| 2.0 | 1.5 | 15.0 |
| 2.5 | 1.5 | 9.0 |
| 1.5 | 1.5 | 12.5 |
| 2.5 | 1.5 | 20.5 |
| 2.0 | 2.0 | 18.0 |
| 2.0 | 1.5 | 7.0 |
| 2.5 | 1.5 | 9.0 |
| 3.5 | 1.5 | 14.5 |
| 3.0 | 2.5 | 19.5 |
| 1.5 | 1.5 | 8.0 |
| 1.5 | 2.0 | 17.0 |
| 3.0 | 1.5 | 7.0 |
| 2.5 | 1.5 | 15.0 |
| 3.0 | 1.5 | 20.0 |
| 2.5 | 1.5 | 11.0 |
| 3.0 | 1.5 | 12.0 |
| 2.0 | 2.5 | 8.5 |
| 3.0 | 1.5 | 17.0 |
| 3.5 | 1.5 | 18.0 |
| 2.5 | 2.5 | 14.5 |
| 2.5 | 1.5 | 16.0 |
| 2.0 | 2.0 | 11.0 |
| 2.0 | 2.0 | 19.5 |
| 2.0 | 2.0 | 7.5 |
| 3.0 | 1.5 | 16.0 |
| 3.0 | 2.0 | 18.0 |
| 2.5 | 2.0 | 16.0 |
| 3.5 | 2.0 | 19.5 |
| 2.0 | 2.0 | 14.0 |
| 3.0 | 1.5 | 18.0 |
| 2.5 | 1.5 | 19.0 |
| 3.5 | 1.5 | 18.0 |
| 3.0 | 2.0 | 15.5 |
| 3.0 | 2.0 | 17.0 |
| 130.0 | 87.5 | 716.5 |
| Av. 2.6 | Av. 1.8 | Av. 14.3 |

**PICEA EXCELSA NO. IV.**

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 4.0 cm. | 2.0 cm. | 17.0 cm. |
| 3.5 | 2.0 | 14.0 |
| 3.5 | 2.0 | 15.5 |
| 3.5 | 2.0 | 10.0 |
| 4.5 | 2.0 | 18.5 |
| 4.0 | 2.0 | 14.0 |
| 3.0 | 1.5 | 16.0 |
| 3.0 | 2.5 | 14.5 |
| 1.5 | 1.5 | 18.0 |
| 3.5 | 2.0 | 9.5 |
| 3.0 | 1.5 | 12.0 |
| 5.0 | 2.0 | 11.0 |
| 2.5 | 1.5 | 9.5 |
| 3.0 | 2.0 | 12.5 |
| 5.5 | 3.0 | 12.5 |
| 2.5 | 1.5 | 18.0 |
| 2.5 | 2.0 | 10.0 |
| 2.0 | 2.0 | 18.5 |
| 3.5 | 2.5 | 8.5 |
| 5.0 | 1.5 | 13.5 |
| 3.5 | 2.0 | 17.0 |
| 3.5 | 1.5 | 14.0 |
| 3.0 | 2.0 | 10.5 |
| 4.0 | 2.0 | 19.0 |
| 4.0 | 2.0 | 14.0 |
| 2.5 | 2.0 | 18.5 |
| 3.0 | 2.0 | 17.5 |
| 2.5 | 2.0 | 17.0 |
| 3.5 | 1.5 | 20.5 |
| 4.0 | 2.0 | 15.5 |
| 2.5 | 2.0 | 8.5 |
| 2.5 | 2.0 | 9.5 |
| 4.0 | 2.0 | 16.0 |
| 4.0 | 2.0 | 14.5 |
| 4.5 | 2.0 | 13.0 |
| 5.5 | 2.0 | 16.0 |
| 4.0 | 1.5 | 15.5 |
| 6.5 | 1.5 | 14.5 |
| 2.5 | 2.0 | 11.0 |
| 2.5 | 2.0 | 15.5 |
| 1.5 | 2.0 | 9.5 |
| 2.5 | 1.5 | 11.5 |
| 4.0 | 1.5 | 12.5 |
| 4.5 | 1.5 | 11.5 |
| 3.5 | 1.5 | 14.0 |
| 2.0 | 2.0 | 15.5 |
| 2.0 | 1.5 | 8.0 |
| 3.0 | 2.0 | 9.5 |
| 2.0 | 1.5 | 11.0 |
| 2.0 | 1.5 | 11.0 |
| 167.5 | 93.5 | 664.5 |
| Av. 3.4 | Av. 1.9 | Av. 13.3 |

Picea excelsa tap root lengths, as indicated by the preceding theoretical curves would, at 10-day intervals, be as follows:

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| June 28 .................... | 1.5 cm. | 1.5 cm. | 1.5 cm. | 1.5 cm. |
| July 8 ...................... | 1.8 | 2.6 | 2.9 | 2.8 |
| July 18 ..................... | 2.2 | 3.7 | 4.4 | 4.0 |
| July 28 ..................... | 2.6 | 4.8 | 5.8 | 5.4 |
| August 7 ................... | 3.0 | 6.0 | 7.3 | 6.7 |
| August 17 .................. | 3.3 | 7.0 | 8.7 | 8.0 |
| August 27 .................. | 3.7 | 8.2 | 10.2 | 9.3 |
| September 6 ............... | 4.1 | 9.3 | 11.7 | 10.7 |
| September 16 .............. | 4.4 | 10.5 | 13.1 | 12.0 |
| September 26 .............. | 4.8 | 11.6 | 14.6 | 13.3 |

### PINUS RESINOSA.

The seeds of Pinus resinosa were planted in the spring of 1916 (April 27). Owing to the ravages of a damping off fungus, the seedlings

were very scarce in some parts of the bed. This hindered subsequent measurements. The results on Pinus resinosa are only partial and are given only for what they may be worth.

Measurements taken June 28, 1916, were as follows:

Nos. I, II. III, IV.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 2.0 cm. | 1.5 cm. |
| 1.5 | 2.5 | 2.0 |
| 3.0 | 4.5 | 3.5 |
| Av. 1.5 | Av. 2.2 | Av. 1.7 |

On July 5, 1916, the measurements taken were as follows:

No. I.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 1.5 cm. | 3.0 cm. | 2.5 cm. |
| 1.5 | 2.5 | 2.7 |
| 3.0 | 5.5 | 5.2 |
| Av. 1.5 | Av. 2.7 | Av. 2.6 |

No. III.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 cm. | 2.5 cm. | 3.7 cm. |
| 2.0 | 3.0 | 3.0 |
| 4.0 | 5.5 | 6.7 |
| Av. 2.0 | Av. 2.7 | Av. 3.3 |

No. II.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 | 3.0 | 2.2 |
| 2.0 | 3.0 | 1.6 |
| 4.0 | 6.0 | 3.8 |
| Av. 2.0 | Av. 3.0 | Av. 1.9 |

No. IV.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 | 1.7 | 2.0 |
| 2.0 | 2.0 | 3.0 |
| 4.0 | 3.7 | 5.0 |
| Av. 2.0 | Av. 1.8 | Av. 2.5 |

Measurements made July 12, 1916, were:

No. I.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 cm. | 1.5 cm. | 5.0 cm. |
| 2.0 | 2.5 | 4.5 |
| 4.0 | 4.0 | 9.5 |
| Av. 2.0 | Av. 2.0 | Av. 4.7 |

No. III.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.5 cm. | 3.0 cm. | 6.0 cm. |
| 2.0 | 2.0 | 2.5 |
| 4.5 | 5.0 | 8.5 |
| Av. 2.2 | Av. 2.5 | Av. 4.2 |

No. II.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 | 1.5 | 6.5 |
| 2.0 | 1.5 | 6.0 |
| 4.0 | 3.0 | 12.5 |
| Av. 2.0 | Av. 1.5 | Av. 6.2 |

No. IV.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 | 2.5 | 4.5 |
| 2.0 | 2.5 | 5.5 |
| 4.0 | 5.0 | 10.0 |
| Av. 2.0 | Av. 2.5 | Av. 5.0 |

On August 9, 1916, measurements were made, but on Bed IV only, due to the fact that the removal of seedlings from the other three beds would not have left enough for satisfactory final measurements.

No. IV.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.5 cm. | 2.8 cm. | 14.0 cm. |
| 2.5 | 3.0 | 9.0 |
| 2.2 | 2.7 | 9.5 |
| 2.0 | 3.0 | 14.0 |
| 2.5 | 2.7 | 9.0 |
| 2.5 | 2.5 | 14.0 |
| 2.0 | 2.5 | 14.0 |
| 2.5 | 3.0 | 15.0 |
| 2.3 | 2.3 | 13.5 |
| 21.0 | 24.3 | 112.0 |
| Av. 2.3 | Av. 2.7 | Av. 12.4 |

The final measurements made August 29, 1916, were:

PINUS RESINOSA I.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.0 cm. | 2.5 cm. | 2.0 cm. |
| 2.0 | 2.0 | 6.0 |
| 4.0 | 4.5 | 8.0 |
| Av. 2.0 | Av. 2.2 | Av. 4.0 |

PINUS RESINOSA II.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 2.5 cm. | 2.5 cm. | 6.0 cm. |
| 3.0 | 3.0 | 7.5 |
| 3.0 | 3.5 | 8.5 |
| 2.5 | 3.5 | 4.0 |
| 11.0 | 12.5 | 26.0 |
| Av. 2.8 | Av. 3.1 | Av. 6.5 |

PINUS RESINOSA III.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 3.0 cm. | 3.5 cm. | 11.0 cm. |
| 3.5 | 4.0 | 12.0 |
| 3.0 | 3.5 | 14.0 |
| 3.0 | 3.0 | 12.0 |
| 3.0 | 3.0 | 12.5 |
| 2.5 | 3.5 | 15.0 |
| 3.0 | 2.5 | 12.5 |
| 3.0 | 3.0 | 8.5 |
| 3.5 | 3.5 | 7.0 |
| 3.0 | 3.5 | 13.0 |
| 3.0 | 3.0 | 11.0 |
| 3.0 | 3.0 | 9.0 |
| 2.5 | 3.0 | 15.0 |
| 2.5 | 3.5 | 6.5 |
| 3.0 | 4.0 | 6.5 |
| 2.5 | 3.0 | 10.0 |
| 3.0 | 3.5 | 8.5 |
| 3.0 | 3.5 | 12.0 |
| 2.5 | 3.5 | 7.0 |
| 3.0 | 3.0 | 10.5 |
| 3.0 | 3.5 | 14.0 |
| 2.5 | 3.5 | 13.0 |
| 3.0 | 3.0 | 12.5 |
| 3.5 | 4.5 | 9.5 |
| 3.5 | 4.0 | 13.5 |
| 3.0 | 4.0 | 9.0 |
| 2.5 | 3.5 | 10.0 |
| 2.5 | 4.0 | 10.0 |
| 2.5 | 3.0 | 4.0 |
| 2.5 | 3.5 | 5.5 |
| 3.0 | 3.5 | 9.5 |
| 2.5 | 2.5 | 10.0 |
| 2.5 | 3.5 | 9.5 |
| 3.0 | 3.0 | 9.5 |
| 2.5 | 3.5 | 10.0 |
| 3.0 | 3.0 | 6.0 |
| 108.5 | 121.5 | 368.0 |
| Av. 2.9 | Av. 3.4 | Av. 10.2 |

PINUS RESINOSA IV.

| Top. | Hypocotyl. | Tap Root. |
|---|---|---|
| 3.0 cm. | 3.0 cm. | 11.0 cm. |
| 3.0 | 3.0 | 11.0 |
| 2.5 | 4.0 | 7.5 |
| 3.0 | 3.5 | 13.5 |
| 2.5 | 3.0 | 12.0 |
| 3.0 | 3.0 | 18.0 |
| 3.0 | 2.5 | 12.0 |
| 2.5 | 3.5 | 12.0 |
| 2.5 | 3.0 | 13.5 |
| 3.0 | 3.0 | 10.5 |
| 3.0 | 3.0 | 17.0 |
| 3.0 | 3.5 | 20.0 |
| 2.5 | 2.5 | 10.5 |
| 3.0 | 3.5 | 20 0 |
| 3.0 | 3.5 | 17.5 |
| 2.5 | 2.5 | 14.0 |
| 3.0 | 3.5 | 12.0 |
| 3.0 | 3.0 | 15.5 |
| 3.0 | 3.5 | 19.0 |
| 3.0 | 2.5 | 21.5 |
| 3.0 | 3.0 | 11.0 |
| 2.5 | 3.5 | 12.0 |
| 3.0 | 2.5 | 18.0 |
| 3.0 | 3.0 | 13.0 |
| 3.5 | 3.5 | 14.5 |
| 3.5 | 3.5 | 12.5 |
| 2.5 | 3.5 | 14.0 |
| 3.5 | 4.0 | 19.5 |
| 3.0 | 3.5 | 15.0 |
| 3.5 | 3.5 | 15.0 |
| 3.0 | 2.5 | 16.0 |
| 3.0 | 3.0 | 16.0 |
| 2.5 | 3.0 | 11.5 |
| 3.0 | 2.5 | 12.0 |
| 2.5 | 3.0 | 15.0 |
| 2.5 | 3.5 | 10.0 |
| 3.0 | 3.5 | 11.5 |
| 2.5 | 2.5 | 15.0 |
| 2.0 | 3.0 | 10.0 |
| 3.0 | 2.5 | 16.0 |
| 3.5 | 3.5 | 10.0 |
| 2.5 | 3.0 | 15.0 |
| 2.5 | 2.5 | 11.0 |
| 2.5 | 3.5 | 9.5 |
| 2.5 | 2.0 | 12.5 |
| 2.5 | 3.5 | 9.0 |
| 2.5 | 2.0 | 15.0 |
| 3.0 | 3.0 | 16.0 |
| 2.5 | 3.5 | 8.0 |
| 2.5 | 3.0 | 10.5 |
| 140.5 | 154.0 | 682.0 |
| Av. 2.8 | Av. 3.1 | Av. 13.6 |

Pinus resinosa tap root lengths, as indicated by the preceding theoretical curves, would, at 10-day intervals, be as follows:

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| June 28 | 1.7 cm. | 1.7 cm. | 1.7 cm. | 1.7 cm. |
| July 8 | 1.9 | 2.2 | 2.6 | 2.9 |
| July 18 | 2.2 | 2.7 | 3.5 | 4.2 |
| July 28 | 2.4 | 3.2 | 4.4 | 5.5 |
| August 7 | 2.6 | 3.7 | 5.3 | 6.8 |
| August 17 | 2.9 | 4.3 | 6.2 | 8.1 |
| August 27 | 3.1 | 4.8 | 7.1 | 9.4 |
| September 6 | 3.4 | 5.3 | 8.1 | 10.7 |
| September 16 | 3.7 | 5.8 | 9.0 | 12.0 |
| September 26 | 3.9 | 6.3 | 9.9 | 13.3 |

The maximum and minimum temperatures of air just above soil as registered in the Pinus strobus experiment are given below. These temperatures are Fahrenheit and are given simply to show the general conditions under which the various beds grew. Cf. Tables I, II, III, IV.

| Date. | I. | II. | III. | IV. |
|---|---|---|---|---|
| July 13 | 92 max. | 96 max. | 106 max. | 106 max. |
| | 62 min. | 60 min. | 53 min. | 62 min. |
| July 14 | 99 | 99 | 102 | 103 |
| | 67 | 65 | 62 | 67 |
| July 15 | None taken. | | | |
| July 16 | 102 | 103 | 111 | 115 |
| | 71 | 73 | 65 | 72 |
| July 17 | 97 | 96 | 106 | 105 |
| | 69 | 66 | 62 | 67 |
| July 18 | 101 | 101 | 112 | 114 |
| | 72 | 68 | 66 | 68 |
| July 19 | 101 | 104 | 111 | 117 |
| | 73 | 71 | 68 | 74 |
| July 20 | 93 | 92 | 95 | 94 |
| | 68 | 64 | 62 | 76 |
| July 21 | 95 | 100 | 107 | 107 |
| | 62 | 59 | 56 | 60 |
| July 22 | 99 | 102 | 109 | 107 |
| | 62 | 61 | 58 | 67 |
| July 23 | 100 | 103 | 112 | 115 |
| | 64 | 61 | 57 | 69 |
| July 24 | 103 | 104 | 107 | 118 |
| | 67 | 64 | 67 | 65 |
| July 25 | 103 | 106 | 111 | 118 |
| | 67 | 64 | 62 | 66 |
| July 26 | 101 | 104 | 112 | 116 |
| | 71 | 68 | 63 | 70 |
| July 27 | 103 | 106 | 111 | 112 |
| | 73 | 70 | 68 | 73 |
| July 28 | ? | ? | 111 | 112 |
| | | | 68 | 70 |
| July 29 | 108 | 110 | 112 | 118 |
| | 75 | 73 | 70 | 73 |
| July 30 | 103 | 105 | 110 | 111 |
| | 77 | 75 | 72 | 79 |
| July 31 | 92 | 95 | 106 | 105 |
| | 62 | 60 | 63 | 57 |
| August 1 | 93 | 92 | 103 | 102 |
| | 52 | 46 | 48 | 44 |
| August 2 | 95 | 95 | 106 | 105 |
| | 65 | 62 | 66 | 58 |
| August 3 | 95 | 95 | 100 | 97 |
| | 65 | 62 | 64 | 59 |
| August 4 | 100 | 100 | 110 | 108 |
| | 73 | 71 | 74 | 69 |
| August 5 | 95 | 98 | 105 | 106 |
| | 74 | 72 | 75 | 69 |
| August 6 | 98 | 100 | 107 | 106 |
| | 77 | 75 | 78 | 78 |
| August 7 | 98 | 94 | 102 | 101 |
| | 74 | 71 | 77 | 68 |
| August 8 | 86 | 93 | 102 | 106 |
| | 62 | 58 | 61 | 55 |
| August 9 | 69 | 91 | 103 | 101 |
| | 61 | 58 | 61 | 55 |
| August 10 | 87 | 89 | 97 | 96 |
| | 71 | 70 | 72 | 68 |
| August 11 | 98 | 89 | 100 | 99 |
| | 56 | 54 | 56 | 51 |

| Date. | I. | II. | III. | IV. |
|---|---|---|---|---|
| August 12 | None taken. | | | |
| August 13 | 77 | 88 | 93 | 92 |
| | 50 | 45 | 46 | 42 |
| August 14 | ? | ? | 82 | 80 |
| | | | 50 | 44 |
| August 15 | 87 | 87 | 106 | 106 |
| | 64 | 62 | 65 | 59 |
| August 16 | 98 | 95 | 104 | 108 |
| | 62 | 59 | 62 | 56 |
| August 17 | 94 | 94 | 102 | 102 |
| | 66 | 63 | 65 | 59 |
| August 18 | ? | ? | 97 | 96 |
| | 70 | 69 | 71 | 66 |
| August 19 | 100 | 102 | 112 | 110 |
| | 69 | 66 | 68 | 63 |
| August 20 | 108 | 107 | 115 | 111 |
| | 71 | 68 | 69 | 64 |
| August 21 | 102 | 108 | 115 | 111 |
| | 75 | 74 | 74 | 60 |
| August 22 | 90 | 92 | 99 | 98 |
| | 56 | 54 | 56 | 51 |
| August 23 | 81 | 90 | 99 | 98 |
| | 56 | 53 | 58 | 50 |
| August 24 | 88 | 90 | 98 | 97 |
| | 55 | 52 | 53 | 49 |
| August 25 | 68 | 69 | 78 | 70 |
| | 51 | 47 | 50 | 45 |
| August 26 | None taken. | | | |
| August 27 | 74 | 79 | 88 | 88 |
| | 45 | 41 | 39 | 37 |
| August 28 | 81 | 88 | 92 | 91 |
| | 51 | 47 | 48 | 43 |
| August 29 | 82 | 86 | 94 | 94 |
| | 55 | 52 | 54 | 49 |
| August 30 | 85 | 88 | 96 | 96 |
| | 55 | 52 | 54 | 49 |
| August 31 | 87 | 88 | 94 | 91 |
| September 1 | 85 | 89 | 98 | 99 |
| | 55 | 52 | 53 | 49 |
| September 2 | 77 | 84 | 95 | 93 |
| | 44 | 39 | 40 | 36 |
| September 3 | 79 | 88 | 92 | 90 |
| | 57 | 56 | 52 | 58 |
| September 4 | 82 | 88 | ? | 85 |
| | 65 | 64 | | 62 |
| September 5 | 88 | 91 | 105 | 108 |
| | 64 | 62 | 65 | 59 |
| September 6 | 89 | 95 | 102 | 102 |
| | 67 | 64 | 66 | 61 |
| September 7 | None taken. | | | |
| September 8 | 81 | 88 | 96 | 94 |
| | 48 | 44 | 45 | 41 |
| September 9 | 84 | 90 | 101 | 98 |
| | 52 | 48 | 50 | 45 |
| September 10 | None taken. | | | |
| September 11 | 92 | 93 | 100 | 99 |
| | 62 | 60 | 66 | 67 |
| September 12 | 91 | 92 | 98 | ? |
| | 65 | 62 | 64 | 59 |
| September 13 | 78 | 83 | 92 | 93 |
| | 61 | 59 | 62 | 57 |
| September 14 | 81 | 82 | 76 | 78 |
| | 47 | 52 | 49 | 58 |
| September 15 | 62 | 62 | 70 | 66 |
| | 47 | 44 | 42 | 40 |
| September 16 | 63 | 63 | 66 | 63 |
| | 42 | 38 | 38 | 34 |
| September 17 | 67 | 67 | 76 | 77 |
| | 48 | 48 | 51 | 47 |
| September 18 | 63 | 67 | 74 | 76 |
| | 37 | 31 | 37 | 37 |
| September 19 | 70 | 72 | 78 | 77 |
| | 35 | 28 | 28 | 25 |
| September 20 | 80 | 82 | 88 | 87 |
| | 47 | 45 | 47 | 48 |
| September 21 | 74 | 75 | 84 | 81 |
| | 54 | 53 | 52 | 51 |
| September 22 | 70 | 70 | 74 | 72 |
| | 47 | 46 | 48 | 48 |
| September 23 | 69 | 70 | 76 | 75 |
| | 43 | 42 | 43 | 39 |
| September 24 | 70 | 75 | 80 | 80 |
| | 38 | 35 | 38 | 33 |

## SUMMARY.

It is somewhat hazardous to express a definite opinion on the advisability of growing seedlings with no shade and no water from the economic standpoint, before the mortality per cent due to transplanting and passing the winter has been ascertained. If the percentage is no higher, or but a little higher, in the case of III than in Nos. II and IV, then No. III is clearly the advisable and economic method in this locality. If, however, No. IV shows a much lower mortality, then the extra expense incurred in daily watering is justifiable. Experiments to determine this mortality rate are now being conducted and will be reported on at their completion in the spring. General botanical studies would indicate in advance that No. III would suffer less from a severe winter than either II or IV, as these seedlings have had their tissues brought to a mature condition early by a medium condition of moisture, whereas those which were either shaded or watered will enter the winter in less resistant condition.

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# APPENDIX.

## KITCHIN ON GROWTH OF SEEDLINGS.

### Table I.

**U. S. Department of Agriculture, Weather Bureau,**
**Charles F. Marvin, Chief.**

MONTHLY METEOROLOGICAL SUMMARY.

**Lansing, Michigan, June, 1916.**

| Date. | Temp. Highest. | Temp. Lowest. | Temp. Mean. | Precipitation (in inches). | Character of day. | Percentage of possible sunshine. |
|---|---|---|---|---|---|---|
| 1... | 73 | 43 | 58 | 0 | Pt. Cloudy | 80 |
| 2... | 74 | 55 | 64 | 0.13 | Pt. Cloudy | 69 |
| 3... | 68 | 49 | 58 | 0 | Clear | 84 |
| 4... | 73 | 49 | 61 | 0.01 | Pt. Cloudy | 61 |
| 5... | 71 | 48 | 60 | 0 | Pt. Cloudy | 96 |
| 6... | 69 | 50 | 60 | 0.14 | Cloudy | 57 |
| 7... | 58 | 51 | 54 | 0.61 | Cloudy | 3 |
| 8... | 61 | 52 | 56 | 0.29 | Cloudy | 18 |
| 9... | 63 | 53 | 58 | 0.20 | Cloudy | 29 |
| 10... | 67 | 49 | 58 | 0 | Cloudy | 53 |
| 11... | 74 | 50 | 62 | 0 | Pt. Cloudy | 73 |
| 12... | 76 | 50 | 63 | 0 | Pt. Cloudy | 100 |
| 13... | 81 | 52 | 66 | 0 | Clear | 89 |
| 14... | 69 | 57 | 63 | 0.38 | Cloudy | 24 |
| 15... | 76 | 55 | 66 | 0.25 | Pt. Cloudy | 77 |
| 16... | 69 | 54 | 62 | 0.50 | Cloudy | 66 |
| 17... | 66 | 54 | 60 | 0.80 | Pt. Cloudy | 68 |
| 18... | 70 | 52 | 61 | 0.12 | Pt. Cloudy | 68 |
| 19... | 67 | 44 | 56 | 0 | Pt. Cloudy | 60 |
| 20... | 68 | 41 | 54 | 0.01 | Pt. Cloudy | 83 |
| 21... | 63 | 49 | 56 | 0.13 | Cloudy | 61 |
| 22... | 74 | 49 | 62 | 0 | Pt. Cloudy | 88 |
| 23... | 78 | 53 | 66 | 0.43 | Pt. Cloudy | 62 |
| 24... | 75 | 61 | 68 | 0.06 | Pt. Cloudy | 73 |
| 25... | 76 | 54 | 65 | 0 | Clear | 100 |
| 26... | 80 | 53 | 66 | 0.25 | Cloudy | 61 |
| 27... | 68 | 51 | 60 | 0 | Pt. Cloudy | 50 |
| 28... | 77 | 48 | 62 | 0 | Clear | 100 |
| 29... | 79 | 56 | 68 | 0.43 | Cloudy | 82 |
| 30... | 78 | 58 | 68 | 1.15 | Pt. Cloudy | 60 |
| 31... | .. | .. | .. | .... | ........... | .... |

Mean highest temp. ................71.4
Mean lowest temp. ..................51.3
Mean temp. for month ..............61.4
Total precip. for month ............5.89

**WEATHER.**

Number days clear ................. 4
Partly cloudy ..................... 16
Cloudy ............................ 10
With 0.01 or more of precipitation 18

**SUNSHINE.**

Number hours sunshine ...........304.6
Possible hours sunshine ...........459.4
Percentage of possible ............ 66

**BAROMETER.**

Mean .......................29.87 inches
Highest............30.34 inches, on 22nd
Lowest .............29.39 inches, on 7th

This month since 1863.

| Year. | Mean Temp. | Total Precip. |
|---|---|---|
| 1863 | ..... | ..... |
| 1864 | 67.6 | 3.88 |
| 1865 | 70.3 | 3.55 |
| 1866 | 66.6 | 5.37 |
| 1867 | 71.6 | 2.88 |
| 1868 | 68.5 | 3.55 |
| 1869 | 64.4 | 4.40 |
| 1870 | 70.9 | 7.27 |
| 1871 | 68.2 | 2.98 |
| 1872 | 71.8 | 3.45 |
| 1873 | 70.6 | 2.96 |
| 1874 | 70.6 | 5.07 |
| 1875 | 66.6 | 1.84 |
| 1876 | 68.1 | 4.34 |
| 1877 | 65.9 | 3.58 |
| 1878 | 64.1 | 3.15 |
| 1879 | 66.0 | 2.87 |
| 1880 | 67.6 | 5.04 |
| 1881 | 64.3 | 4.37 |
| 1882 | 66.5 | 5.57 |
| 1883 | 65.9 | 11.35 |
| 1884 | 68.9 | 2.88 |
| 1885 | 64.7 | 6.01 |
| 1886 | 65.7 | 1.92 |
| 1887 | 68.5 | 2.47 |
| 1888 | 67.9 | 2.51 |
| 1889 | 62.8 | 3.42 |
| 1890 | 70.3 | 3.92 |
| 1891 | 67.4 | 2.55 |
| 1892 | 67.7 | 4.38 |
| 1893 | 66.6 | 4.85 |
| 1894 | 71.4 | 1.30 |
| 1895 | 71.4 | 1.01 |
| 1896 | 69.9 | 2.60 |
| 1897 | 64.2 | 2.57 |
| 1898 | 67.6 | 4.91 |
| 1899 | 68.2 | 1.15 |
| 1900 | 65.2 | 2.57 |
| 1901 | 68.0 | 3.57 |
| 1902 | 61.8 | 7.28 |
| 1903 | ..... | 6.28 |
| 1904 | 65.6 | 2.49 |
| 1905 | 66.2 | 7.47 |
| 1906 | 67.1 | 4.61 |
| 1907 | 65.0 | 2.37 |
| 1908 | 70.0 | 1.28 |
| 1909 | 66.7 | 2.86 |
| 1910 | 64.9 | 1.95 |
| 1911 | 68.0 | 3.77 |
| 1912 | 63.1 | *0.97* |
| 1913 | 67.6 | 1.01 |
| 1914 | 66.0 | 4.11 |
| 1915 | *61.0* | 3.96 |
| 1916 | 61.4 | 5.89 |

**SUMMARY.**

**TEMPERATURE.**

Highest, 81°, on 13th.
Lowest, 41°, on 20th.
Greatest daily range, 30°, on 1st.
Least daily range, 7°, on 7th.
Normal for month, 61.4°.
Excess or deficiency this month, —5.8°.
Accumulated excess or deficiency since Jan. 1st, —299°; average daily, same period, —1.1°.
Highest in 31 years, 99°; lowest, 34°.

**PRECIPITATION.**

(in inches).

Total amount, 5.89; normal, 3.40; excess or deficiency this month, +1.99; since Jan. 1st, +3.36.
Greatest amount in any 24 hour period, 1.58, on 29th and 30th.
Total snowfall, 0.0 in.

**WIND.**

Prevailing Dir., SW.
Total movement, 3,818 miles; average hourly velocity, 5.3 miles.
Maximum velocity, 21, from the E, on 6th.

**DATES OF—**

Auroras ................ 0
Dense fog .............. 0
Hail ................... 0
Sleet .................. 0
Thunderstorms, 2, 4, 8, 14, 15, 16, 17, 23, 26, 29.
Halos: solar, 6, 15, 29.
lunar ................. 14
Frost: killing .......... 0
heavy .................. 0
light .................. 0

## Table II.

### U. S. Department of Agriculture, Weather Bureau, Charles F. Marvin, Chief.

#### MONTHLY METEOROLOGICAL SUMMARY.

### Lansing, Michigan, July, 1916.

| Date. | Temp. Highest. | Temp. Lowest. | Temp. Mean. | Precipitation (in inches). | Character of day. | Percentage of possible sunshine. | This month since 1863. Year. | Mean Temp. | Total Precip. |
|---|---|---|---|---|---|---|---|---|---|
| 1... | 83 | 55 | 69 | 0 | Pt. Cloudy | 89 | 1863 | ..... | ..... |
| 2... | 86 | 61 | 74 | 0 | Clear | 78 | 1864 | 74.5 | 1.25 |
| 3... | 79 | 57 | 68 | 0 | Clear | 85 | 1865 | 65.6 | 3.91 |
| 4... | 84 | 55 | 70 | 0 | Clear | 100 | 1866 | 71.7 | 4.19 |
| 5... | 84 | 56 | 70 | 0 | Clear | 100 | 1867 | 71.6 | 1.78 |
| 6... | 86 | 57 | 72 | 0 | Clear | 99 | 1868 | 77.2 | 1.11 |
| 7... | 87 | 58 | 72 | 0 | Clear | 100 | 1869 | 70.4 | 5.77 |
| 8... | 82 | 55 | 68 | 0 | Clear | 95 | 1870 | 74.4 | 3.02 |
| 9... | 79 | 52 | 66 | 0 | Clear | 80 | 1871 | 70.6 | 3.10 |
| 10... | 84 | 52 | 68 | 0 | Clear | 100 | 1872 | 74.9 | 3.86 |
| 11... | 91 | 62 | 76 | 0 | Clear | 100 | 1873 | 70.8 | 5.12 |
| 12... | 94 | 69 | 82 | 0 | Pt. Cloudy | 84 | 1874 | 72.0 | 2.56 |
| 13... | 85 | 65 | 75 | 0.05 | Pt. Cloudy | 58 | 1875 | 69.7 | 2.42 |
| 14... | 89 | 60 | 74 | 0 | Clear | 100 | 1876 | 72.5 | 2.10 |
| 15... | 92 | 64 | 78 | 0 | Pt. Cloudy | 91 | 1877 | 71.4 | 2.25 |
| 16... | 91 | 70 | 80 | 0.04 | Pt. Cloudy | 94 | 1878 | 73.0 | 2.96 |
| 17... | 87 | 68 | 78 | 0 | Clear | 100 | 1879 | 74.0 | 2.19 |
| 18... | 90 | 66 | 78 | 0 | Clear | 100 | 1880 | 68.0 | 6.27 |
| 19... | 94 | 68 | 81 | 0 | Clear | 99 | 1881 | 73.1 | 1.81 |
| 20... | 86 | 69 | 78 | 0 | Pt Cloudy | 68 | 1882 | 67.5 | 2.32 |
| 21... | 87 | 65 | 76 | 0 | Clear | 100 | 1883 | 68.9 | 11.27 |
| 22... | 92 | 61 | 76 | 0 | Pt. Cloudy | 89 | 1884 | 68.0 | 2.60 |
| 23... | 91 | 62 | 76 | 0 | Clear | 100 | 1885 | 72.7 | 2.52 |
| 24... | 94 | 61 | 78 | 0 | Clear | 100 | 1886 | 70.7 | 0.65 |
| 25... | 95 | 64 | 80 | 0 | Clear | 100 | 1887 | 75.5 | 1.50 |
| 26... | 95 | 65 | 80 | 0 | Clear | 100 | 1888 | 70.5 | 2.40 |
| 27... | 98 | 69 | 84 | 0 | Clear | 65 | 1889 | 70.2 | 3.41 |
| 28... | 97 | 70 | 84 | 0 | Pt. Cloudy | 76 | 1890 | 71.1 | 0.92 |
| 29... | 102 | 72 | 87 | 0 | Clear | 100 | 1891 | 65.3 | 1.88 |
| 30... | 101 | 74 | 88 | 0 | Clear | 79 | 1892 | 70.8 | 2.00 |
| 31... | 89 | 63 | 76 | 0 | Clear | 98 | 1893 | 71.5 | 1.86 |

| Year. | Mean Temp. | Total Precip. |
|---|---|---|
| 1894 | 73.2 | 0.86 |
| 1895 | 70.5 | 1.47 |
| 1896 | 71.8 | 6.73 |
| 1897 | 73.8 | 3.49 |
| 1898 | 70.0 | 1.84 |
| 1899 | 69.8 | 2.11 |
| 1900 | 69.6 | 4.15 |
| 1901 | 74.2 | 5.08 |
| 1902 | 70.6 | 7.18 |
| 1903 | 67.9 | 3.79 |
| 1904 | 69.2 | 1.97 |
| 1905 | 69.8 | 5.75 |
| 1906 | 70.8 | 2.28 |
| 1907 | 70.0 | 4.80 |
| 1908 | 73.2 | 1.03 |
| 1909 | 70.0 | 2.56 |
| 1910 | 71.0 | 1.58 |
| 1911 | 71.8 | 1.65 |
| 1912 | 69.6 | 5.06 |
| 1913 | 70.8 | 2.85 |
| 1914 | 71.0 | 1.65 |
| 1915 | 67.9 | 5.17 |
| 1916 | 76.1 | *0.09* |

Mean highest temp. ....................89.5
Mean lowest temp. ....................62.7
Mean temp. for month ..............76.1
Total precip. for month..............0.09

**Weather.**

Number days clear .................. 23
Partly cloudy ...................... 8
Cloudy ........................... 0
With 0.01 or more of precipitation.. 2

**Sunshine.**

Number hours sunshine.............424.1
Possible hours sunshine.............464.9
Percentage of possible ............. 91

**Barometer.**

Mean .......................30.00 inches
Highest..............30.22 inches, on 6th
Lowest.............29.68 inches, on 2nd

### SUMMARY.

**Temperature.**

Highest, 102°, on 29th.
Lowest, 52°, on 10th.
Greatest daily range, 33°, on 24th.
Least daily range, 17°, on 20th.
Normal for month, 70.9°.
Excess or deficiency this month, +5.2°.
Accumulated excess or deficiency since Jan. 1st, —134°; average daily, same period, —0.6°.
Highest in 31 years, 102°; lowest, 37°.

**Precipitation**

(in inches).

Total amount, 0.09; normal, 3.22; excess or deficiency this month, —3.13; since Jan. 1st., +0.23.
Greatest amount in any 24 hour period, 0.05, on 13th.
Total snowfall, 0.0 in.

**Wind.**

Prevailing Dir., E.
Total movement, 2,505 miles; average hourly velocity, 3.4 miles.
Maximum velocity, 21, from the NW, on 2nd.

**Dates of—**

Auroras ............... 0
Dense fog .............. 0
Hail .................. 0
Sleet .................. 0
Thunderstorms, 2, 13, 15, 16, 20, 22, 30.
Halos: solar, 1, 28.
lunar ............... 0
Frost: killing .......... 0
heavy ............... 0
light ................ 0

# Table III.

## U. S. Department of Agriculture, Weather Bureau, Charles F. Marvin, Chief.

### MONTHLY METEOROLOGICAL SUMMARY.

### Lansing, Michigan, August, 1916.

| Date. | Temp. Highest. | Temp. Lowest. | Temp. Mean. | Precipitation (in inches). | Character of day. | Percentage of possible sunshine. | This month since 1863. Year. | Mean Temp. | Total Precip. |
|---|---|---|---|---|---|---|---|---|---|
| 1... | 81 | 55 | 68 | 0 | Clear | 96 | 1863 | ..... | 3.00 |
| 2... | 87 | 49 | 68 | 0 | Clear | 100 | 1864 | 70.7 | 0.89 |
| 3... | 90 | 62 | 76 | 0 | Cloudy | 44 | 1865 | 65.8 | 3.38 |
| 4... | 92 | 64 | 78 | 0 | Pt. Cloudy | 73 | 1866 | 62.6 | 3.44 |
| 5... | 89 | 70 | 80 | 0.23 | Clear | 76 | 1867 | 69.8 | 1.74 |
| 6... | 94 | 72 | 83 | 0 | Clear | 94 | 1868 | 70.3 | 2.42 |
| 7... | 93 | 70 | 82 | 0.63 | Pt. Cloudy | 52 | 1869 | 70.6 | 4.85 |
| 8... | 83 | 66 | 74 | 0 | Pt. Cloudy | 54 | 1870 | 70.1 | 4.53 |
| 9... | 82 | 59 | 70 | 0 | Clear | 100 | 1871 | 71.2 | 1.42 |
| 10... | 85 | 59 | 72 | 0.22 | Pt. Cloudy | 68 | 1872 | 71.2 | 4.18 |
| 11... | 85 | 63 | 74 | 0 | Cloudy | 38 | 1873 | 69.5 | 0.80 |
| 12... | 82 | 55 | 68 | 0.02 | Pt. Cloudy | 82 | 1874 | 69.4 | 1.28 |
| 13... | 73 | 50 | 62 | 0.14 | Clear | 100 | 1875 | 65.5 | 1.47 |
| 14... | 71 | 45 | 58 | 0 | Cloudy | 66 | 1876 | 71.6 | 1.28 |
| 15... | 81 | 48 | 64 | 0 | Pt. Cloudy | 75 | 1877 | 68.5 | 6.57 |
| 16... | 87 | 62 | 74 | 0 | Pt. Cloudy | 76 | 1878 | 70.2 | 1.85 |
| 17... | 90 | 60 | 75 | 0 | Pt. Cloudy | 87 | 1879 | 70.0 | 1.61 |
| 18... | 88 | 65 | 76 | 0.11 | Cloudy | 48 | 1880 | 68.6 | 6.02 |
| 19... | 96 | 70 | 83 | 0 | Pt. Cloudy | 100 | 1881 | 72.7 | 1.63 |
| 20... | 98 | 68 | 83 | 0 | Clear | 100 | 1882 | 69.5 | 5.72 |
| 21... | 96 | 68 | 82 | 0 | Clear | 100 | 1883 | 64.9 | 0.18 |
| 22... | 88 | 61 | 74 | 0 | Clear | 100 | 1884 | 66.9 | 1.80 |
| 23... | 78 | 52 | 65 | 0 | Clear | 98 | 1885 | 68.6 | 6.75 |
| 24... | 86 | 54 | 70 | 0.07 | Clear | 83 | 1886 | 69.3 | 4.69 |
| 25... | 79 | 52 | 66 | 0 | Clear | 94 | 1887 | 68.0 | 0.89 |
| 26... | 65 | 54 | 60 | 0.16 | Cloudy | 0 | 1888 | 67.6 | 1.87 |
| 27... | 71 | 45 | 58 | 0 | Clear | 93 | 1889 | 68.6 | 0.68 |
| 28... | 75 | 41 | 58 | 0 | Clear | 92 | 1890 | 65.4 | 3.60 |
| 29... | 80 | 49 | 64 | 0 | Clear | 98 | 1891 | 67.9 | 4.82 |
| 30... | 81 | 54 | 68 | 0 | Clear | 98 | 1892 | 68.3 | 5.12 |
| 31... | 83 | 54 | 68 | 0 | Pt. Cloudy | 72 | 1893 | 68.1 | 0.56 |
| | | | | | | | 1894 | 68.8 | 00.0 |
| | | | | | | | 1895 | 71.2 | 4.64 |
| | | | | | | | 1896 | 70.0 | 4.73 |
| | | | | | | | 1897 | 65.9 | 1.69 |
| | | | | | | | 1898 | 69.0 | 2.73 |
| | | | | | | | 1899 | 71.4 | 0.70 |
| | | | | | | | 1900 | 73.3 | 2.98 |
| | | | | | | | 1901 | 68.4 | 2.49 |
| | | | | | | | 1902 | 64.2 | 0.68 |
| | | | | | | | 1903 | 64.3 | 6.73 |
| | | | | | | | 1904 | 65.9 | 3.26 |
| | | | | | | | 1905 | 69.6 | 3.92 |
| | | | | | | | 1906 | 73.5 | 4.35 |
| | | | | | | | 1907 | 65.5 | 2.87 |
| | | | | | | | 1908 | 68.4 | 3.99 |
| | | | | | | | 1909 | 71.0 | 1.61 |
| | | | | | | | 1910 | 68.2 | 1.76 |
| | | | | | | | 1911 | 68.2 | 1.48 |
| | | | | | | | 1912 | 65.7 | 2.19 |
| | | | | | | | 1913 | 69.4 | 5.60 |
| | | | | | | | 1914 | 68.9 | 3.33 |
| | | | | | | | 1915 | 68.4 | 3.63 |
| | | | | | | | 1916 | 71.0 | 1.58 |

Mean highest temp. ....................84.2
Mean lowest temp. ....................57.9
Mean temp. for month ..................71.0
Total precip. for month...............1.58

**WEATHER.**

Number days clear .................. 16
Partly cloudy .................... 10
Cloudy ........................... 5
With 0.01 or more of precipitation.. 8

**SUNSHINE.**

Number hours sunshine ............340.2
Possible hours sunshine ............430.7
Percentage of possible ............ 79

**BAROMETER.**

Mean .......................30.01 inches
Highest...............30.29 inches, on 1st
Lowest .............29.68 inches, on 24th

## SUMMARY

**TEMPERATURE.**

Highest, 98°, on 20th.
Lowest, 41°, on 28th.
Greatest daily range, 38°, on 2nd.
Least daily range, 11°, on 26th.
Normal for month, 68.4°.
Excess or deficiency this month, +2.6°.
Accumulated excess or deficiency since Jan. 1st, —52°; average daily, same period, —0.2°.
Highest in 31 years, 99°; lowest, 32°.

**PRECIPITATION (in inches).**

Total amount, 1.58; normal, 2.63; excess or deficiency this month, —1.05; since Jan. 1st, —0.82.
Greatest amount in any 24 hour period, 0.63, on 7th.
Total snowfall, 0.0 in.

**WIND.**

Prevailing Dir., SW.
Total movement, 2,859 miles; average hourly velocity, 3.8 miles.
Maximum velocity, 19, from the W, on 3rd.

**DATES OF—**

Auroras .............. 26
Dense fog ............ 0
Hail .................. 0
Thunderstorms, 3, 4, 7, 8, 10, 16, 18.
Halos: solar, 4, 17, 18, 19, 27, 31.
lunar ............... 0
Frost: killing ......... 0
heavy ............... 0
light ................ 28

## Table IV.

### U. S. Department of Agriculture, Weather Bureau, Charles F. Marvin, Chief.

**MONTHLY METEOROLOGICAL SUMMARY.**

### Lansing, Michigan, September, 1916.

| Date. | Temp. Highest. | Temp. Lowest. | Temp. Mean. | Precipitation (in inches). | Character of day. | Percentage of possible sunshine. |
|---|---|---|---|---|---|---|
| 1... | 75 | 62 | 68 | 0.01 | Cloudy | 3 |
| 2... | 71 | 48 | 60 | 0 | Clear | 98 |
| 3... | 76 | 41 | 58 | 0 | Clear | 100 |
| 4... | 80 | 56 | 68 | 0.10 | Cloudy | 27 |
| 5... | 84 | 64 | 74 | 0.03 | Pt. Cloudy | 61 |
| 6... | 87 | 64 | 76 | 0 | Pt. Cloudy | 77 |
| 7... | 88 | 67 | 78 | 0.10 | Cloudy | 42 |
| 8... | 78 | 52 | 65 | 0 | Pt. Cloudy | 68 |
| 9... | 79 | 46 | 62 | 0 | Clear | 98 |
| 10... | 77 | 50 | 64 | 0 | Pt. Cloudy | 66 |
| 11... | 86 | 62 | 74 | 0 | Clear | 98 |
| 12... | 87 | 65 | 76 | 0 | Clear | 87 |
| 13... | 74 | 52 | 63 | 0.04 | Pt. Cloudy | 67 |
| 14... | 70 | 51 | 60 | 0 | Pt. Cloudy | 45 |
| 15... | 60 | 43 | 52 | 0 | Pt. Cloudy | 80 |
| 16... | 57 | 39 | 48 | 0 | Pt. Cloudy | 58 |
| 17... | 60 | 37 | 48 | 0.03 | Pt. Cloudy | 66 |
| 18... | 62 | 33 | 48 | 0 | Pt. Cloudy | 81 |
| 19... | 69 | 30 | 50 | 0 | Pt. Cloudy | 80 |
| 20... | 78 | 46 | 62 | 0 | Clear | 99 |
| 21... | 70 | 49 | 60 | 0.01 | Pt. Cloudy | 86 |
| 22... | 66 | 47 | 56 | 0 | Cloudy | 21 |
| 23... | 64 | 41 | 52 | 0 | Pt. Cloudy | 33 |
| 24... | 69 | 39 | 54 | 0 | Pt. Cloudy | 61 |
| 25... | 78 | 44 | 61 | 0 | Clear | 100 |
| 26... | 74 | 55 | 64 | 0.38 | Cloudy | 0 |
| 27... | 71 | 59 | 65 | 1.34 | Cloudy | 0 |
| 28... | 67 | 49 | 58 | 0.13 | Cloudy | 30 |
| 29... | 50 | 31 | 40 | 0 | Pt. Cloudy | 39 |
| 30... | 62 | 30 | 46 | 0 | Clear | 96 |
| 31... | .. | .. | .. | .... | ........... | .... |

Mean highest temp. ....................72.3
Mean lowest temp. ....................48.4
Mean temp. for month ...............60.2
Total precip. for month ...............2.17

**WEATHER.**

| | |
|---|---|
| Number days clear ................. | 8 |
| Partly cloudy ...................... | 15 |
| Cloudy ........................... | 7 |
| With 0.01 or more of precipitation.. | 10 |

**SUNSHINE.**

| | |
|---|---|
| Number hours sunshine ............ | 223.1 |
| Possible hours sunshine ............ | 374.8 |
| Percentage of possible .............. | 59 |

**BAROMETER.**

Mean .......................30.02 inches
Highest..............30.37 inches, on 3rd
Lowest..............29.62 inches, on 27th

**This month since 1863.**

| Year. | Mean Temp. | Total Precip. |
|---|---|---|
| 1863 | ..... | 0.89 |
| 1864 | 59.6 | 2.58 |
| 1865 | 67.7 | 4.79 |
| 1866 | 55.8 | 5.80 |
| 1867 | 56.6 | 1.42 |
| 1868 | 58.8 | 2.95 |
| 1869 | 68.5 | 1.48 |
| 1870 | 68.7 | 2.85 |
| 1871 | 59.1 | 0.79 |
| 1872 | 62.0 | 5.21 |
| 1873 | 67.4 | 3.50 |
| 1874 | 62.8 | 1.27 |
| 1875 | 58.5 | 2.89 |
| 1876 | 56.3 | 3.65 |
| 1877 | 61.3 | 1.38 |
| 1878 | 63.2 | 3.41 |
| 1879 | 56.2 | 3.19 |
| 1880 | 55.8 | 3.10 |
| 1881 | 69.7 | 2.91 |
| 1882 | 59.9 | 0.67 |
| 1883 | 56.4 | 2.34 |
| 1884 | 65.1 | 3.34 |
| 1885 | 58.9 | 3.75 |
| 1886 | 63.1 | 5.40 |
| 1887 | 58.9 | 4.73 |
| 1888 | 57.8 | 1.89 |
| 1889 | 61.2 | 0.79 |
| 1890 | 57.7 | 1.67 |
| 1891 | 65.1 | 1.10 |
| 1892 | 60.8 | 2.17 |
| 1893 | 58.4 | 1.84 |
| 1894 | 63.7 | 2.59 |
| 1895 | 66.6 | 0.85 |
| 1896 | 57.6 | 6.73 |
| 1897 | 62.9 | 0.80 |
| 1898 | 63.3 | 3.00 |
| 1899 | 57.0 | 2.14 |
| 1900 | 68.2 | 0.89 |
| 1901 | 61.7 | 1.67 |
| 1902 | 58.7 | 5.88 |
| 1903 | 61.0 | 2.86 |
| 1904 | 62.0 | 2.35 |
| 1905 | 63.8 | 3.21 |
| 1906 | 67.5 | 0.76 |
| 1907 | 61.8 | 4.68 |
| 1908 | 66.4 | 0.65 |
| 1909 | 60.4 | 1.51 |
| 1910 | 60.2 | 2.74 |
| 1911 | 61.5 | 5.05 |
| 1912 | 62.7 | 3.33 |
| 1913 | 61.0 | 1.53 |
| 1914 | 60.3 | 2.65 |
| 1915 | 63.2 | 6.55 |
| 1916 | 60.2 | 2.17 |

**SUMMARY.**

**TEMPERATURE.**

Highest, 88°, on 7th.
Lowest, 30°, on 19th.
Greatest daily range, 39°, on 19th.
Least daily range, 12°, on 27th.
Normal for month, 61.6°.
Excess or deficiency this month, —1.4°.
Accumulated excess or deficiency since Jan. 1st, —89°; average daily, same period, —0.3°.
Highest in 31 years, 99°; lowest, 21°.

**PRECIPITATION.**

(in inches).

Total amount, 2.17; normal, 2.62; excess or deficiency this month, —0.45; since Jan. 1st., —1.27.
Greatest amount in any 24 hour period, 1.34, on 27th.
Total snowfall, 0.0 in.

**WIND.**

Prevailing Dir., SW.
Total movement, 3,916 miles; average hourly velocity, 5.4 miles.
Maximum velocity, 20, from the SW, on 27th.

**DATES OF—**

| | |
|---|---|
| Auroras ............... | 0 |
| Dense fog ............ | 0 |
| Hail .................. | 0 |
| Thunderstorms, 4, 7, 21, 26, 27. | |
| Halos: solar, 10, 19. | |
| lunar ............... | 0 |
| Frost: killing ........ | 19 |
| heavy ............... | 18 |
| light ............... | 0 |

Department of Botany, Michigan Agricultural College.

## LEGENDS.

A photograph of the Picea excelsa bed, taken after the completion of the experiment and intended to convey an accurate idea of the method of procedure. The burlap covered portion is that known as I; the next, covered by the lath, is II; the third is exposed, and is the check plot. This is designated as III. Part IV extends to the stick at the extreme right of the picture. The other species (Pinus strobus and Pinus resinosa) were treated in identically the same manner.

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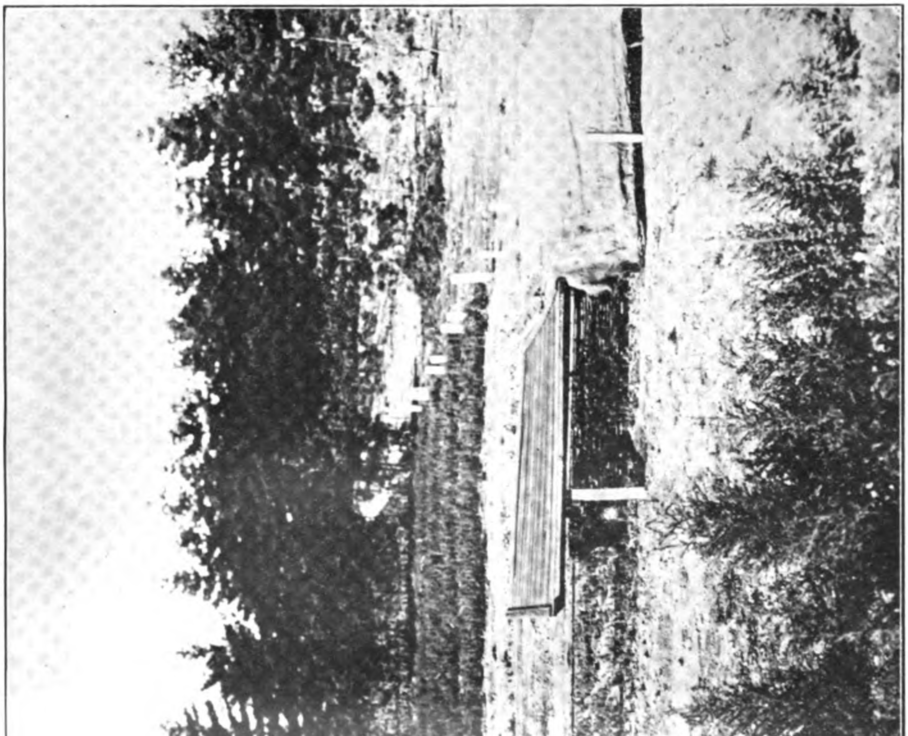
| | |
|---|---|
| Plate XVII. | A photograph of the Picea excelsa bed, taken after the completion of the experiment and intended to convey an accurate idea of the method of procedure. |
| Plate XVIII. | Fig. 1. Bunches of Pinus strobus grown under the different conditions.<br>Fig. 2. Typical individuals of above bunches. |
| Plate XIX. | Taproot development of Pinus strobus. |
| Plate XX. | Fig. 1. Bunches of Picea excelsa grown under the different conditions.<br>Fig. 2. Typical individuals of above bunches. |
| Plate XXI. | Taproot development of Picea excelsa. |
| Plate XXII. | Typical individuals of Pinus resinosa. |
| Plate XXIII. | Taproot development of Pinus resinosa. |



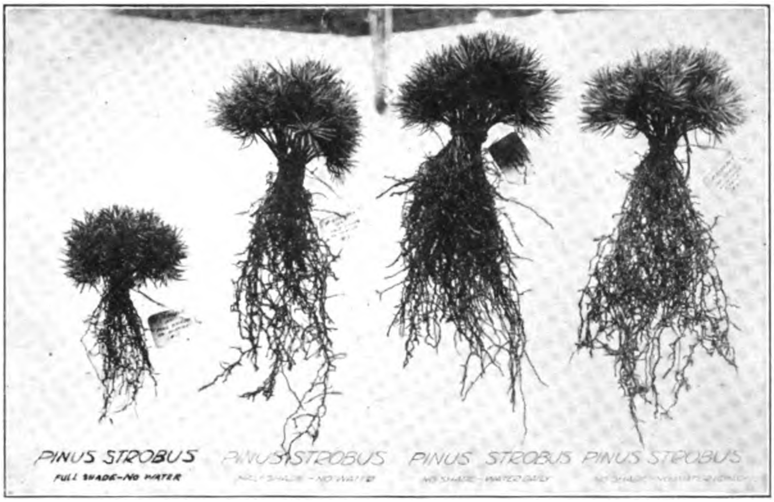



Figure 1.

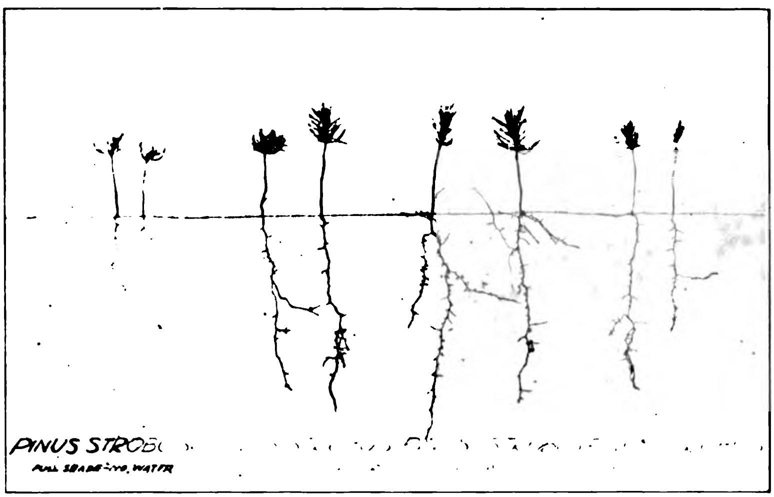
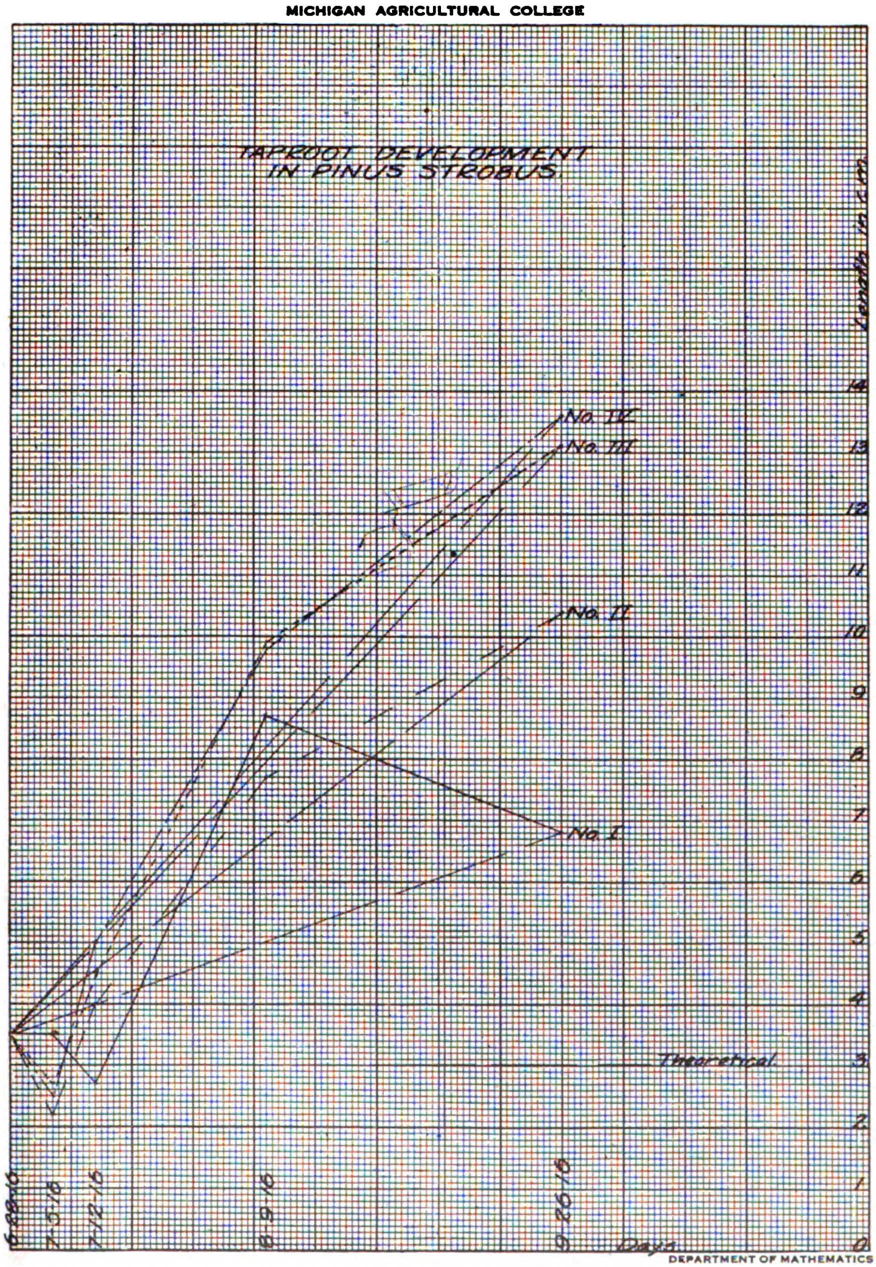


Figure 2.


MICHIGAN AGRICULTURAL COLLEGE
TAPROOT DEVELOPMENT
IN PINUS STROBUS.
Length in c.m.
No. IV
No. III
No. II
No. I
Theoretical
6-28-16
7-5-16
7-12-16
8-9-16
9-26-16
Days
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DEPARTMENT OF MATHEMATICS

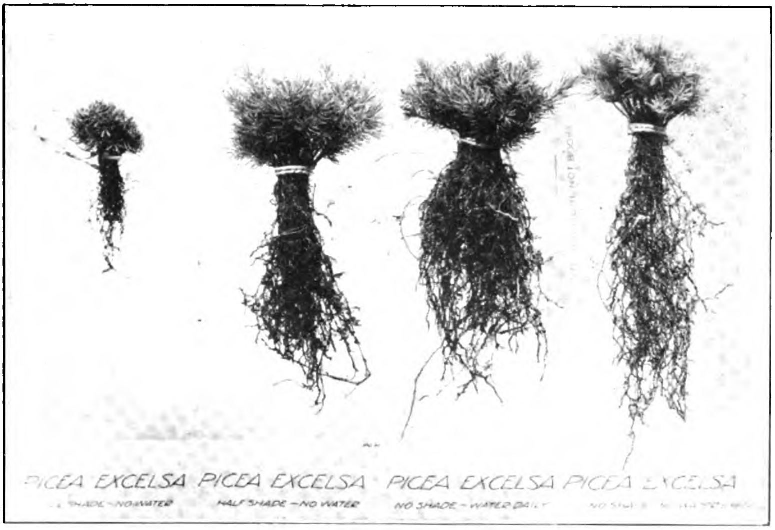



Figure 1.

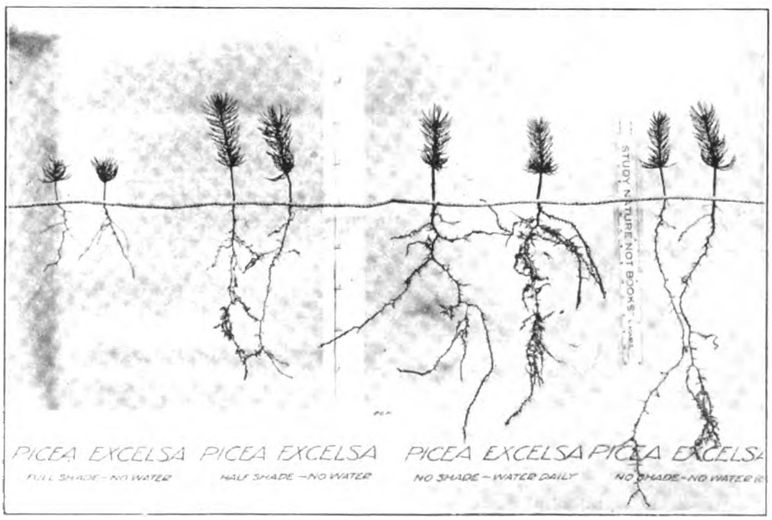
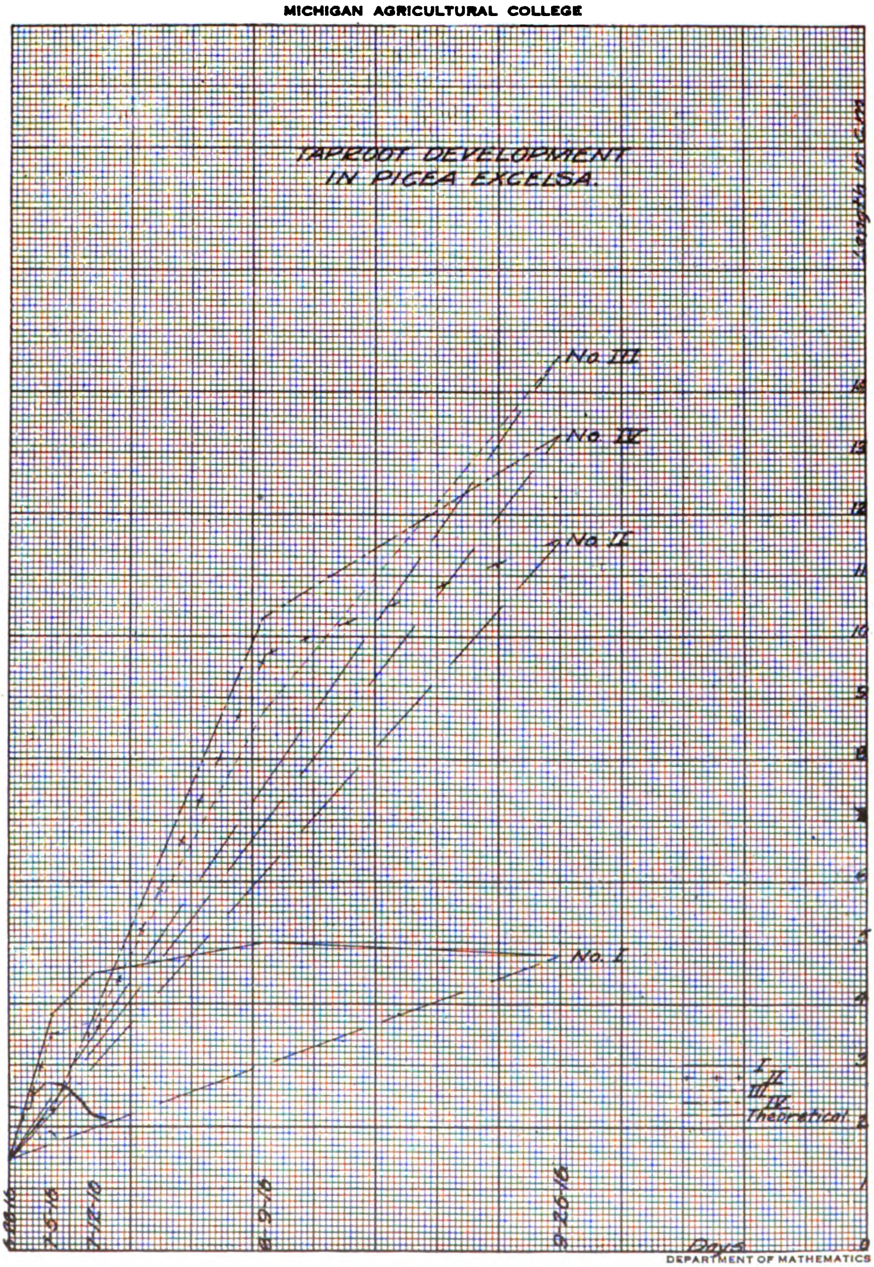
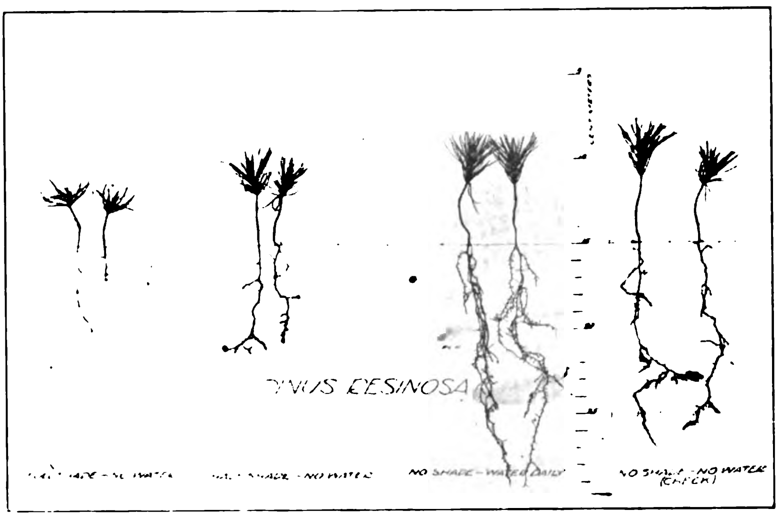
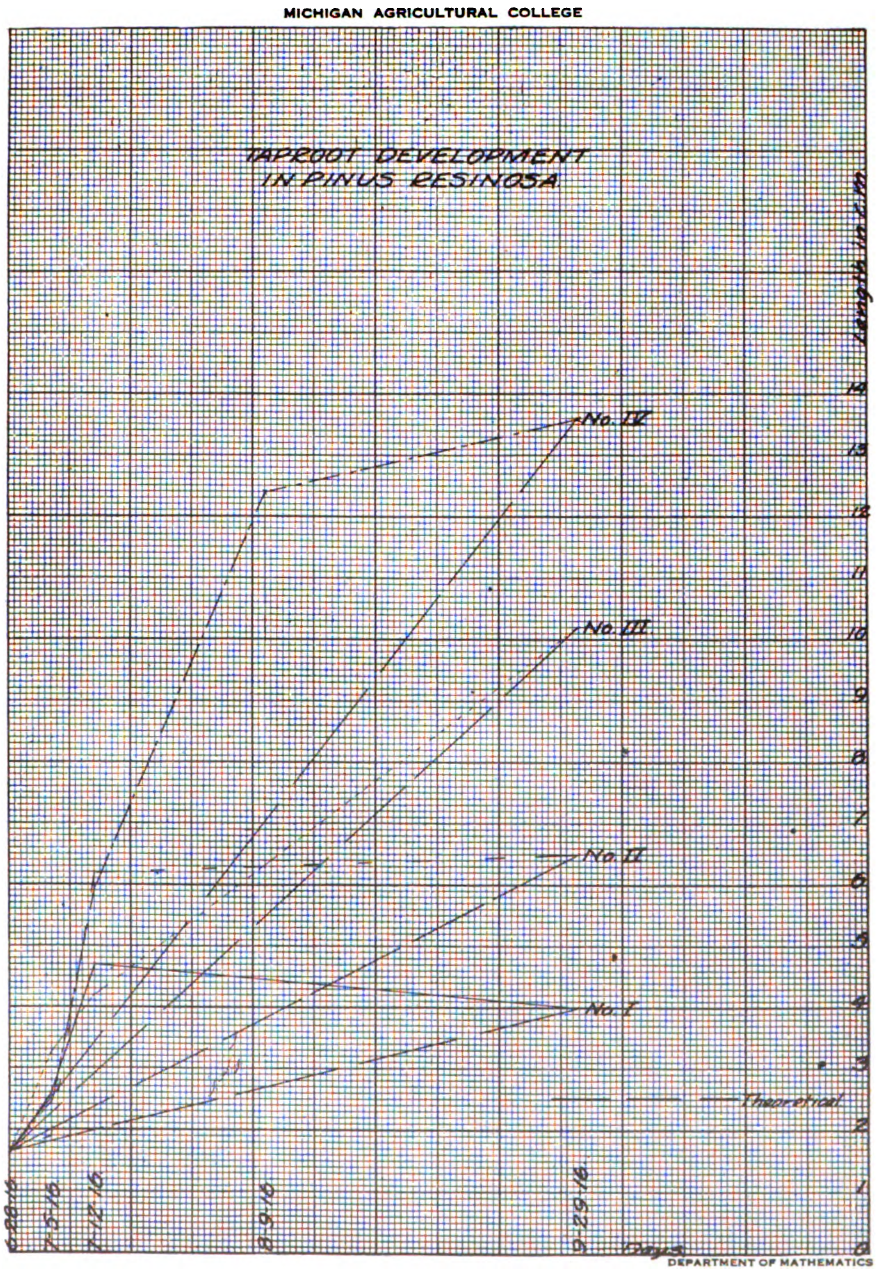



Figure 2.


MICHIGAN AGRICULTURAL COLLEGE
TAPROOT DEVELOPMENT
IN PICEA EXCELSA.
No. III
No. IV
No. II
No. I
Theoretical
Days
DEPARTMENT OF MATHEMATICS


NO SHADE – WATER DAILY


MICHIGAN AGRICULTURAL COLLEGE
TAPROOT DEVELOPMENT
IN PINUS RESINOSA
Length in C.M.
No. IV
No. III
No. II
No. I
Theoretical
6.28.16
7.5.16
7.12.16
8.9.16
9.29.16
Days
DEPARTMENT OF MATHEMATICS